Patricia F. Waller (1970). North Carolina Symposium on Highway Safety (Vol. 2). Highway and Traffic Safety: a problem of definition. Chapel Hill, NC: University of North Carolina Highway Safety Research Center.

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raleigh, n.c.

spring 1970 ● volume two ● edited by Patricia F. Waller

Highway and Traffic Safety: a problem of definition

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North Carolina Symposium
on highway safety

volume two

Highway and Traffic Safety: a problem of definition

Murray Blumenthal *University of Denver*

Discussant: Elmer Oettinger

David Solomon *Federal Highway Administration*

Discussant: B. J. Campbell

Kenneth J. Tharp *Cornell Aeronautical Laboratory, Inc.*

Discussant: Wesley Grigg Mullen

NORTH CAROLINA SYMPOSIUM ON HIGHWAY SAFETY

Raleigh, N. C.

Volume two **Spring 1970**

The University of North Carolina Highway Safety Research Center
Chapel Hill, North Carolina 27514 • B. J. Campbell, Director

highway safety: a problem of definition . . .

The first step in solving a problem, as we all know, is defining it. Is highway safety a social problem that pervades the fabric of our status-seeking, speed-loving, conveniency-oriented culture? Can we call it a "systems" problem and place the primary responsibility for failure on the driver who is, after all, the "thinking" element of the system? Is our so-called balanced approach to highway safety paying off; that is, are traditional, widely accepted programs panning out in terms of accidents prevented and lives saved? Is the lack of coordination at the decision-making level a problem of inadequate knowledge, insufficient power as a result of fragmentation of efforts, or both? The consensus is that highway safety merits a second look and a new working definition that is both comprehensive and rational.

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About the Center . . .

At the request of the Governor of North Carolina, the 1965 North Carolina State Legislature provided for the establishment of the University of North Carolina Highway Safety Research Center. Dr. B. J. Campbell, then Head of the Accident Research Branch of Cornell Aeronautical Laboratory, was invited to return to his alma mater to direct the new Center. He accepted, and in 1966 the Center officially began operation. Since then the staff has grown to more than fifty, representing skills in experimental psychology, clinical psychology, mathematics, transportation engineering, computer systems, journalism, library science, biostatistics, graphic arts, epidemiology, experimental statistics, general engineering, human factors engineering, and health administration. The University of North Carolina Highway Safety Research Center is the first institution in the South devoted exclusively to research in highway safety.

About the Symposium . . .

The North Carolina Symposium on Highway Safety is a semiannual event sponsored by the North Carolina State University School of Engineering, the University of North Carolina School of Public Health, and the University of North Carolina Highway Safety Research Center. First held in the fall of 1969, the symposium has three major purposes. First, it is designed to attract students to acquaint them with the problems and possibilities for research in the field of highway safety.

Second, it is a means of bringing together professional workers in the greater North Carolina area whose interests are related to this field.

And, third, the published papers from the symposium will provide on a regular basis major positions and summaries of research in the field of highway safety. It is hoped that these volumes will provide ready resource material for persons interested in this field.

INTRODUCTION

This symposium was the first to be held on the campus of North Carolina State University, the home of the School of Engineering which cosponsors these meetings. Our speakers and topics were chosen to reflect the interests represented on this campus. Two of the three major speakers are engineers, while the third is a strong advocate of engineering solutions to highway safety problems.

All three papers stress the importance of analyzing the highway safety dilemma in order to develop appropriate countermeasures, but each one takes a different tack. Dr. Blumenthal's major point is that the way we define the problem of traffic safety to a large extent determines the kinds of solutions we seek. He reviews some of the approaches that have been taken, including the "nut behind the wheel" approach; the engineering, enforcement, and education approach; and the systems approach. He evaluates the effects of each and then proposes that a more fruitful approach might be to consider highway safety as a social problem.

The crashes, he holds, are the symptoms of this social problem, the tip of an iceberg. Moving down the proverbial iceberg, he examines the underlying system that produces the crashes. Our highways are the end result of an evolutionary process that began as animal paths. Now these paths are traveled by high-powered vehicles with poorly trained operators. Poor signing, poor visibility, and poor feedback all serve to enhance the danger of the driving task. Our emphasis has been on demanding better performance from the driver rather than on developing a system that is more forgiving of error. We know that many drivers are unskilled or suffer from serious physical or mental conditions. Yet we expect them to compensate for shortcomings in other parts of the system.

Beyond the system lie the laws, agencies and people that manage the system. Here there is no single management but a segmented system with little or no coordination. The lack of coordination is confounded by inadequate knowledge on which to base a rational, comprehensive program. Underlying the entire structure is our value system which idealizes speed, status, power, and convenience without examining the price we pay in return. We have shown only a token response to the traffic safety problem, and Dr. Blumenthal foresees no change in the near future.

Defining traffic safety as a social problem, he feels, would underscore the futility of studying only one part of the problem and would emphasize the need for a comprehensive program that takes into account the role of management, legislation, the motivations of key decision makers, and the values of a society that supports the entire system.

Dr. Oettinger, discussing this paper, strongly endorses Dr. Blumenthal's concern with the political and social philosophies underlying and determining any safety program, but he warns against expecting miracles from even such a new and comprehensive approach. Keenly aware of the political realities, both in terms of the public's expectations and the pressures from vested interests, Dr. Oettinger anticipates change but feels that we should be more actively preparing for it now if relevant information is to be incorporated into new programs.

Mr. Solomon sets out to debunk a number of highway safety myths that he feels retard the development of effective programs. Like Dr. Blumenthal, he rejects the "nut behind the wheel" philosophy and provides data to refute the idea that a small portion of the population is responsible for most of the accidents over any extended period of time. He presents evidence that high horsepower cars are *not* more dangerous than low horsepower vehicles and seriously challenges the idea that new highways are necessarily safer. He then questions the admonition, "If you drive, don't drink"; he has qualms about the benefits of driver education as currently practiced and about the notion of enforcement leading to greater safety. Other programs that are taken for granted, such as driver licensing and motor vehicle inspection, are also challenged by Mr. Solomon.

Next he reviews what he considers to be useful approaches to highway safety. His recommendations include more freeways and more attention to highway design, as well as changes in the vehicle, improvements in traffic engineering, and safeguards on the roadside. In short, Mr. Solomon is advocating an *unbalanced* safety program that emphasizes research and development, attention to engineering aspects of the problem, and evaluation of existing activities that have not proved their worth, e.g., driver education, enforcement, and driver licensing. Mr. Solomon makes the telling point that the bad safety program drives out the good.

In responding to Mr. Solomon's paper, Dr. Campbell raises two warning flags for those engaged in program evaluation. First, he points out, it should be expected that many programs will have a low benefit/cost ratio. He illustrates this position with the example of seat belts. If the cost of equipping all vehicles with seat belts is weighed against the savings entailed, taking into account the low probability of an accident, the low occupancy rate of vehicles, and the low usage of seat belts, then the seat belt may not appear to be such a sound investment after all. Dr. Campbell also cautions against what is called the Type II error, namely the error of assuming that a program has no real effect when it actually does. This kind of error would lead to the elimination of safety programs that were having some beneficial effect.

It is noteworthy that of our three speakers it was the transportation engineer, not the psychologist, who placed the most emphasis on the role of the driver. Perhaps this reflects the fact that the more one learns about an area the more he realizes how little is known. At the same time one assumes great sophistication on the part of persons working in other areas. While Dr. Blumenthal and Mr. Solomon express pessimism about how much can realistically be expected of the driver, Dr. Tharp looks to the driver as the component of the system that can compensate for shortcomings or deficiencies in other parts of the system.

Dr. Tharp analyzes the highway safety problem in a systems frame of reference and describes the various ways that failure in the system may or may not result in an accident. He provides illustrations of highway conditions that are associated with high rates of failure in the system and suggests ways in which these failures may be combated. Dr. Tharp asks how much cost is justified to reduce highway accidents. Clearly, he surmises, we are not prepared to spend what would be required to eliminate the problem entirely. Consequently, we are back to the question of values that was raised by Dr. Blumenthal. Dr. Tharp advocates correcting major existing highway deficiencies while avoiding their repetition in new construction.

While Dr. Tharp stresses the role of the driver most emphatically, all three speakers concede the importance of studying the driver to provide input to the engineering necessary to improve highways and vehicles. For the engineer to design an efficient vehicle, he must be knowledgeable concerning the limitations of the driver and the variety of drivers likely to be maneuvering his vehicle.

Dr. Mullen picks up on two points in Dr. Tharp's paper and illustrates them from his own experience. First, he considers the effect of environment on accidents as evidenced by design features and their maintenance. Changes made to improve the flow of traffic, he points out, may result in ambiguous cues for the driver and therefore increase the likelihood of accidents. The second point concerns the effect of environment on pavement materials. Here Dr. Mullen describes some of his laboratory research and how it may contribute to decisions that must be made about highway construction.

Mr. Solomon would spend the highway safety dollar on extending the freeway system; Dr. Tharp expresses the most optimism about the driver, although he also emphasizes the improvement of highways; but Dr. Blumenthal calls for a re-examination of the entire social and political system underlying the problem. He feels we would gain more by studying the decision makers rather than the drivers.

We hope that these papers will provide the reader with an appreciation of the breadth of the problem we face as well as the kinds of measures that have been taken with varying degrees of success. The speakers have also suggested provocative ideas for future planning and strategy, some of which hopefully will be implemented.

Patricia F. Waller

Section I

Traffic Safety and the Structure of a Social Problem

Murray Blumenthal

Discussant

Elmer R. Oettinger

MURRAY BLUMENTHAL

Dr. Blumenthal is on the faculty of the College of Law at the University of Denver. He was previously with the Traveler's Research Corporation, where he was Director of the Social Systems Division, supervising and directing research in transportation safety, law enforcement, and community goal setting and planning.

He received a Ph.D. in experimental psychology from the University of Denver, where he taught various psychology courses. He later taught in the California State College system. Subsequently, he joined the National Safety Council and for five years was Director of the Research Department and editor of the *Traffic Safety Research Review.*

Together with Professor H. Lawrence Ross he directed a three year study for the National Highway Safety Bureau (now the National Highway Traffic Safety Administration) on the effectiveness of selected court penalties and programs on driver behavior.

Dr. Blumenthal is on the editorial board of the *Journal of Safety Research* and *Accident Analysis and Prevention.*

It is perhaps not surprising that Dr. Blumenthal views highway safety within the framework of the greater society. He is a man of many talents and broad interests. Before entering the field of psychology and safety, he was an accomplished professional musician.

TRAFFIC SAFETY AND THE STRUCTURE OF A SOCIAL PROBLEM

By Murray Blumenthal

Can you identify the writer of the following paragraphs?

"I propose that our highway system design and operating practice is precisely that which we would have built if our objective had been to kill as many people as possible. We have made a game of it by some qualifications such as 'drive to the right', 'yield to the car on the right at an intersection', 'stop at stop signs', etc. . . .

"A passenger car traveling at legal speeds on a rural highway, where most of our fatal accidents occur, possesses high kinetic energy . . . the kinetic energy of a typical 4,000 pound car is a function of speed. At 60 m.p.h., the car has nearly 500,000 foot-pound kinetic energy, and a 90-m.m. tank weapon projectile has approximately 4,000,000 foot-pounds kinetic energy at the muzzle. Thus, as we drive to Grandmother's house we guide a projectile with kinetic energy equivalent to 165 30.06 deer-rifle bullets, or more than one-tenth that of our best antitank weapon—possibly the equivalent of a 105-m.m. howitzer . . .

"Everyday 20 or 30 or 40 million of us take these missiles out of our garages or carports, and guide them along ribbons of concrete or blacktop to the office, or shop, or school, or shopping center . . . or the corner drugstore, or on a transcontinental vacation. The interesting thing is that, except for a small fraction of this mileage, we are face to face with similar 'ballistic' missiles, with only a 6-inch traffic paint stripe separating us. We don't even fire bowling balls in alternate, opposite directions. Our guidance must always be more precise than the ballistic tables, because only a paint stripe separates opposing streams."

Who wrote these paragraphs? Was it Ralph Nader? Was it Jeffry O'Connell, author of *Safety Last, An Indictment of the Auto Industry* (O'Connell and Myers, 1966)? Was it a student radical, disenchanted with the irrationality, impersonality and destructiveness of our materialistic systems? No, it was none of these. The man who wrote these paragraphs is the automotive safety engineer at the General Motors Technical Center, Kenneth A. Stonex (Stonex, 1965).

Ken Stonex has described for us the state of the motor vehicle transportation system. A system that provides for more violence, crime and anarchy on the streets than all of our other social systems and processes combined. In 1969, 56,400 people were killed and more than three and one-half million were injured on the streets and highways (National Safety Council, 1969); by comparison, in 1967, there were 13,425 homicides (U.S. Department of Commerce, Bureau of Census, 1969). Washington Police Chief Jerry V. Wilson said, in a recent newspaper interview,

> . . . for the white middle class resident of the District of Columbia, traffic accidents cost a great deal more and involve greater risk of death than crime. Your chances of getting home without getting run over by an automobile are a hell of a lot worse than your chances of getting home without being raped or robbed. (Batten, 1970)

The value of such a comparison is limited. But who can deny that we have in our motor vehicle transportation system a problem of serious and threatening dimensions? Perhaps it is not directly threatening to other institutions of society (except in terms of exhaust emissions and waste of resources), but it is a direct and real threat to the individual and to the family. More people die in car and car-pedestrian crashes than in any other circumstance, either disease or accident, from the ages of one through the middle thirties (*Accident Facts,* 1969).

Given a transportation system that exacts an unconscionable cost, what should we do about it? What should we do to reduce the risk as we move from home to work, from home to recreation and to shopping?

Consequences of the Problem Definition

The first thing we ought to do is to make explicit our definition and assumptions about the kind of problem that we believe we are dealing with. Moynihan (Moynihan, 1970) quotes the French philosopher Bernanos as saying, "There are no more corrupting lies than problems poorly stated." Whenever we face a problem, we have beliefs about its nature that influence what we do to try to manage or to solve it. A teacher faced with a slow learning, misbehaving youngster, who tries to improve his learning or to modify his behavior by keeping him after school or by sending him to the vice-principal's office for a reprimand, has certain beliefs about the *kind* of problem she's trying to handle. She probably assumes that this is a problem of defiance and laziness. However, the youngster may have poor hearing or poor eyesight, so that the teacher's assumptions that led to her problem-solving behavior, were at best irrelevant, and at worst destructive to an already punished, confused and failing child.

The 'Nut Behind the Wheel'

What have been some of our assumptions about the traffic safety problem? For a long time, the American public was told: "Drive Safely, the Life You Save May Be Your Own," "Make the Last One-for-the-Road Coffee," etc. (Mendelssohn, 1964). To the extent that this approach is emphasized, there is the assumption that traffic safety is the cumulative result of decisions by individual drivers to drive more carefully and that making these decisions can be encouraged by persuasion through the mass media. In shorthand, this can be described as the "nut behind the wheel" approach. While this approach is attractive in its simplicity and economy, its minimum dislocation of institutions, its appeal to morality, and its enhancement of the sources' feelings of superiority, it has one important failing. It doesn't work. It doesn't work any better than posters in a golf or tennis club that admonish tennis players or golfers to "play skillfully—the game you lose may be your own." Nor would posters or warnings make a great deal of difference for tennis players on an icy court, or for the average golfer approaching a sand trap.

A Problem of Engineering, Enforcement and Education

Another strategy, frequently described by its supporters as a "balanced approach," the "Three E's, Engineering, Enforcement and Education" (Trimble, 1959), similarly tries to modify driver behavior through enforcement and education rather than with the emphasis on persuasion found in the sloganeering approach. The addition of engineering adds a new dimension. However, there is no guiding philosophy or principle that relates the engineering in this context to human behavior. Traditional approaches to engineering that do not understand the limitations and capabilities of the human operator can create more problems than are solved. The engineering that places an exit ramp in close proximity to an entrance ramp sets up a potential conflict situation that will sooner or later exceed the ability of a driver to avoid a crash. The recent Blatnik Committee Hearings provide ample documentation for the existence of booby traps and neglect of the driver's capabilities in the design and signing of the interstate system. A United States Department of Commerce (Miller, 1966) analysis of highway safety concluded that "drivers are being asked to make judgments that they cannot make well; to make decisions faster than humanly possible, and to make changes in direction and speed more accurately than they possibly can."

Another limitation of the 'Three E's' was its interpretation of "engineering" as largely traffic or highway engineering, to the neglect of the vehicle. Also, the selection of engineering, enforcement and education was not based on evidence as to their greater economy and effectiveness than other countermeasures, such as delethalization of the vehicle, improved emergency medical care, etc. The evidence for the effect of enforcement and education on traffic safety is highly unsatisfactory. For example, the problem drinker—a major part of the problem—has not been found in this country to be susceptible to either of these measures, as presently practiced.

Traffic Safety As A Systems Problem

A more recent definition of traffic safety that is finding wide support is the *systems approach*. The A. D. Little (Little, 1966) review of the literature concluded that "the systems nature of the highway safety problem must be appreciated for proper investigation of its components and for the development and evaluation of remedies." The systems approach assumes that a change in one of its components can influence the others, and thereby change total system performance. The approach is also characterized by quantification, model building, empirical testing and attempts at forecasting the effects on the total system, resulting from changes in any one part. Systems thinking also has potential as a safety management tool. A Rand Corporation study (Goeller, 1968) for the National Highway Safety Bureau concluded that "to allocate resources efficiently among different safety activities, we need a prediction model, or set of models, for the traffic safety system that can interrelate the full range of safety oriented activities and predict their consequences . . ." Systems thinking has been applied to the relationship of human performance, the vehicle and the environment by the field of human factors. Specialists in this field assist in designing man-machine systems so that the demands made upon an operator's skills are not beyond his capabilities. Systems concepts are also used in devising mathematical models of traffic flow, of intersections and other traffic patterns. The field of biomechanics reflects system thinking in trying to prevent or reduce injuries in the vehicle by redesigning vehicle interiors and using materials that protect the human body from mechanical energies above body injury thresholds.

The systems definitions of the traffic safety problem are the most promising and sophisticated approaches developed to date. Unfortunately, they assume the essentially rational motivation of the decision makers using the models and formuli. We know, however, that managers of public systems and commercial enterprises are part political, part economic and part rational and non-rational creatures. And we can predict which part gives way when the political, economic and rational parts conflict, as they often do.

A systems approach, if it is to be manageable, must draw boundaries and clearly distinguish between the given system and other systems that comprise its environment. However, societal systems and their problems overlap and intertwine. Problem drinking, poverty, war, drug addiction, etc., all impact heavily on the resources and functioning of the motor vehicle transportation system, but the most rational highway decision-maker is limited to dealing with the *intrusions* of these problems into his system, rather than with their roots, as they may flourish in the system's environment. Systems methodology also assumes the existence of decision-makers with the requisite responsibility and power. However, as we shall see shortly, responsibility for the overall operation of the total motor vehicle transportation system is absent, and management of the various components may have little inclination to consider the relationship of their parts to the whole, and may in fact be in conflict with each other. Despite these limitations, systems techniques have great promise and represent a giant step beyond the moralizing, punitive and fragmented approaches that characterized traffic safety efforts in the past.

Traffic Safety as a 'Social Problem'

In this paper I propose that we describe traffic safety as a "social problem," along with juvenile delinquency, suicide, discrimination, poverty, etc. The elements that generally make up a definition of a social problem are

- a discrepancy or gap between an observed state of affairs and some ideal state.
- the undesirable "situation affecting a significant number of people" (Gould and Koll, 1964).
- the need "for application of social forces and social means for its improvement" (Fairchild, 1957), rather than its yielding to the efforts of individuals acting alone.

Symptom Level

The traffic safety problem meets these three criteria. However, the gap between "what is" and "what should be" is only a symptom. It is the point of the iceberg above the water, with a massive underlying structure. Hack away at the tip with our countermeasures, and the iceberg rises in the water. It was a significant advance, clarifying our thinking about the symptoms, by dividing a crash into a three-phase event (Haddon, 1966): the pre-crash, crash, and post-crash phases. Now we begin to think not only of crash prevention, the first phase, but also of the characteristics of the crash and the need to restrain the human occupants and to improve the crashworthiness of the vehicle and also to provide the emergency medical care and the removal of hazardous debris during the third phase. But it is still only the tip of the structure, as we shall see.

System Level

We move down one step by asking "How are these symptoms—the crashes—produced?" And the answer, described earlier by Stonex, is the system that is "precisely that which we would have built if our objective had been to kill as many people as possible" . . . with twenty-five percent of all drivers, and more than 40 percent of drivers under 24 involved in crashes each year, very predictably, very regularly, as if turned out by a pre-set machine—which it is in a sense, except that nobody set the dial. It just happened.

As described in an earlier paper (Blumenthal, 1969)

> Today's motor vehicle transportation system is the product of a gradual evolution that began when the

> earliest people walked along existing animal paths. Soon they added crude sleds that they dragged along the paths—sometimes helped by animals. Much later they added wheels to the sleds and devised carts and wagons. Then engines replaced the animals—engines that had the power of hundreds of animals. Some of the modified wagons weigh more than two tons, and with their increasingly powerful engines today hurtle past each other on the smoothed and widened animal paths at speeds up to seventy or eighty miles an hour, separated only by six inches of white paint.

The task of driving these vehicles has been described as more demanding than piloting a plane, except for certain flying maneuvers. The highway vehicle is less forgiving of errors than almost any other transportation mode. The consequences of brief inattention or other errors may be disastrous.

Nevertheless, there is no effective system of screening or monitoring the drivers of these vehicles, some of whom are juveniles, or fatigued, or distracted, or mentally ill, or emotionally upset, or suicidal, or homicidal, in addition to any combination of these characteristics, as well as inebriated or under the influence of drugs.

While there are many rules of the road intended to guide drivers, with penalties for their violation, only a very small percentage of those breaking the rules are observed or apprehended, a small percentage of the time (Platt, 1965). Further, penalties for breaking the rules are applied without evidence as to their actual effect on driving behavior (Cramton, 1968).

There is evidence that signs placed along the highways are not understood by a significant percentage of the drivers. Some of the signs give directions without time to act on them, or are helpful only for those already familiar with the locality, or give directions that are not always consistent with other signs.

The roadways are designed so that at times exiting vehicles have to cross the paths of entering vehicles. Sometimes the exit lanes are on the left and sometimes on the right. Some merging lanes are very short and others become the outside right-hand lane (Highway Safety Design and Operations, 1968).

The driver attempts to avoid simultaneously occupying the same space as other vehicles, or pedestrians, or to avoid impacting fixed objects that line the roads. In order to do this he often requires a clear field of vision for 360 degrees. However, his vehicle provides considerably less visibility. Sudden, strong brake pressures at high speeds can lead to wheels locking, so that he may inadvertently change lanes or leave the road, sometimes sideways. In constructing the vehicle, every attempt is made to insulate the driver from the sound of the engine and "feel" of the road, thus encouraging an unconscious tendency to increase speed. At night, at normal highway driving speeds, vehicles consistently overrun their headlights. This means that by the time a driver sees an object on the road in the light from his headlights, it often is too late to stop.

In presenting the vehicle for sale, the manufacturers emphasize nonrational attributes, promising the purchaser the sensation and illusion of youthfulness, daring, popularity, sexuality, aggressiveness, as well as economy and safety.

In actuality, the vehicle has been designed so that during crash stops, the unbelted driver continues forward until he impacts the windshield, its frame, or a steel column pointed directly at his chest, only recently modified to cushion the impact. Two vehicles, vying for the simultaneous occupation of the same space, may inter-penetrate or otherwise demolish each other and their occupants. Testimony by William Haddon before a Senate Subcommittee (Haddon, 1969) reported an average estimated damage of almost seven hundred dollars for both vehicles in front-into-side crashes at only 10 miles per hour. Representatives of General Motors revealed that bumpers on their cars were built to withstand impacts up to only 2.7 miles per hour.

Under some weather conditions, speeds and spacing, it is possible for 40 or more vehicles to be involved in the same chain-reaction crash. In a recent chain-reaction crash, the last vehicle was fifteen miles away from the lead vehicle at the instant of the first impact, with no reasonable maneuver available to the driver that would enable him to escape the crash.

Until the creation of the National Highway Safety Bureau in 1966, safety programs aimed at the drivers in this system had largely moral overtones and assumed that "if only drivers were perfect" then accidents wouldn't happen. This is in sharp contrast to the industrial safety principle: "Anticipate every type of accident which may occur because of machine or human failure and then establish safeguards to eliminate the hazard or minimize the injury when failure occurs."

Industrial safety programs attempt to prevent injuries by eliminating the necessity of perfection, or 100 percent alertness, and cooperation by the worker, and by using mechanical and automatic safeguards whenever feasible to guard the worker against the consequences of his inevitable errors. Rational industrial systems are designed to be "forgiving" of errors, in contrast with the motor vehicle.

Each year, an increasing number of vehicles is fed into the system, and greeted as a sign of economic success. However, in the United States, the system fails more than 10,000 times per day, inflicting death or injury in the process.

A mother will rarely leave a child perched on an unprotected window ledge. There is some indication that fear of height is experienced quite early (Gibson and Walk, 1964) and may be largely unlearned. On the other hand, the same mother may allow a child to stand unrestrained on the front seat of a vehicle moving 60 miles per hour. Evolution appears to have prepared us to appreciate the dangers associated with height, but not with velocities far beyond those attained by the unaided musculature in walking or running.

We have arrived at today's system through an uncontrolled evolution that has resulted in a mismatch between human capabilities and system demands. The configurations that were manageable at lesser speeds and densities are no longer practical.

It is illuminating to examine the assumptions underlying the operation of the motor vehicle transportation system (Blumenthal, 1968):

> First, the system assumes that its users are capable of making rational decisions and acting on them. However, there is ample evidence that at any given time, a significant number of drivers are under the influence of alcohol. Driving following drinking appears to be involved in approximately 50 percent of the fatal collisions. In addition, is there any doubt that drivers classified as normal, mentally healthy, etc., by any set of criteria will at times make decisions under stress, fatigue, or impulse that they

later view as nonrational? Is it unreasonable to assume that troubled drivers, suffering from mild to severe emotional difficulties, will more often make nonrational decisions than other drivers?

MacDonald (MacDonald, 1964) reports a disproportionate representation of former psychiatric hospital patients among those believed to be responsible for fatal highway crashes in Colorado over a three-month period. In a study in the State of Washington (Crancer and Quiring, 1968) of the driving records of former mental patients, "three years before they were hospitalized and three years after, selected diagnostic groups were found to have statistically higher accident rates than a corresponding population group . . . of the same age and sex composition," but with the amounts of driving by the various groups not controlled.

Second, the system assumes that its users are experienced or skilled. However, as reported earlier, more than 40 percent of the drivers under 24 are involved in crashes each year. While alcohol, immaturity or other factors may also contribute to this total, it is obvious that a higher error rate accompanies the earlier stages of learning a psycho-motor skill. Unfortunately, the consequences of such inevitable errors are costly when they result in automobile crashes.

Third, the system assumes that its users are free from severe medical conditions. A study by West, *et al.* (West, *et al.*, 1968), in California, reported that "15 percent, of the drivers dying within 15 minutes of their single-vehicle accidents, died of natural causes—primarily coronary artery disease." Waller (Waller, 1967) reported that "drivers with cardiovascular disease, diabetes, epilepsey, alcoholism, and mental illness had almost twice as many accidents per million miles of driving as did drivers of similar age who were not known to have any medical conditions." Further, "that people with these conditions (excluding the alcoholism group) comprise about 15 percent of the driving population . . ."

Continuing in this vein, the sensory limitations of the older driver, his attention span, perception, integration of information, fatigue effects, drug effects, etc., are cited, but there is one over-riding assumption that is worth examining. This assumption holds that the driver is expected to compensate for the deficiencies of the other elements of the system—the vehicle, the highway, traffic controls and other drivers. The driving strategy of compensating for these other limitations is sometimes called "defensive driving." This assumption, in placing the major responsibilities on the human in the system, is in sharp contrast to the industrial safety principle discussed earlier. In the industrial setting, enlightened management expects and provides for human limitations rather than expecting the human to compensate for the major limitations of his surroundings. This may account, in part, for the recent insurance report (Metropolitan Life Insurance, 1968) that, "differentials in occupational mortality have narrowed—stemming in part—from new operating procedures and better equipment that offer increased protection against . . . hazards." The same report points out that one of the exceptions to the downward trend in occupational groups is among truck drivers, whose accidental death rate in recent years "has actually been some 10 percent higher than it was about a generation ago."

I have described the symptoms of the traffic safety problem, the characteristics of the transportation system that produce these symptoms and how the system evolved. Now when we ask "Why did the system evolve to its present state?" we move one level further into the structure of the social problem.

'Management' Level

Th next level down is the "management" level. We look for the laws, the agencies and the people that manage the system. And, of course, our first finding is that there is no "management." Instead, there are *many* managements, each responsible for a segment of the system and functionally isolated from each other. There is no central responsibility for coordinating the components of the system, not in their conception, design, construction, operation or maintenance. Changes in the vehicle may occur, such as driver eye level and subsequent sight distance, that immediately make obsolete thousands of miles of highway and signs, designed for an earlier sight distance.

A major responsibility for controlling driver behavior has been assigned to the police, who have no role in the design of the separate elements nor in their coordination. Their influence on drivers is based on law and administrative codes that

• until recently required the driver to compensate for deficiencies in highway and vehicle design, while virtually ignoring these latter components and their interaction.

• did not provide for systematic feedback as to the actual versus the hoped-for effects of the laws.

• did not provide for the reduction of crash consequences through requirements of vehicle crashworthiness or a "forgiving" highway environment.

• did not require adequate emergency medical care for the inevitable and predictable injuries that occur on the streets and highways.

Until the promulgation of standards by the National Highway Safety Bureau (U.S. Department of Transportation, 1969), regulation of the motor vehicle transportation system tended to be biased against the driver, based on mythology, with no provision for self-correction, and with significant areas left to chance, such as emergency medical care, the removal of crash debris, and the coordination of the design of the various components.

At the state level a study of Peat, Marwick and Livingston (Peat. Marwick, Livingston & Co., 1968) concluded that

> the activities of highway safety currently cross many departmental lines, creating unusual organizational complexity. The problems associated with having each department develop and pursue its own programs include duplication of traffic records, omissions of key programs and widespread noncompliance with Highway Safety Standards. The establishment of a central program organization, with authority to assist in developing, evaluating, funding and reviewing departmental programs, could effectively meet these problems.

Why hasn't a management been created that could effectively coordinate the components of the motor vehicle transportation system so that the destructive and costly consequences of the system are reduced? The answer to this question brings us down to the foundational level.

Foundational Level

We do not have the *knowledge* that would enable us to significantly reduce the traffic safety problem, given the present resources and constraints. The A. D. Little study (Little, 1966) concluded that "there is no single factor identified in the literature which can be labeled a principal 'cause' of highway hazard, and which can be remedied to reduce traffic accident losses markedly."

During fiscal years 1967-68 and -69, the NHSB allocated 25.5 million dollars, or more than 44 percent of its appropriated budget, for research and for test facilities (U.S. Department of Transportation, 1968) in a desperate attempt to make up for decades of neglect and to learn more about the nature of the problem.

Perhaps more importantly, we do not know how to structure *self-renewing* institutions. Even if we start with adequate understanding and effectively manage a problem, we do not know how to prevent our institutions from becoming increasingly ineffective and irrelevant; as vested interests, rigidity and ignorance take over. We do not know how to transmit research findings to decision-makers without long delays—often years—before the findings are used.

The other component of the foundational level is *values*. We support what we value. We value speed, style, autonomy, profits, convenience, mobility, status, power, privacy, etc. We believe that the motor vehicle supports these values. We have not explicitly examined what other values we give up in order to achieve them. What we give up are more than 55,000 lives, and the freedom from pain, disability or disfigurement for more than three million people each year.

Illustrating the conflict of values underlying the rational regulation of the system was the testimony before a Subcommittee of the Senate Judiciary Committee on the advisability of licensing auto-mechanics (New York Times, 1969). Testimony before the Committee, based on a study by an independent testing center in Denver, reported that by testing 5,000 cars before and after repairs, they found that "only one in 100 had been properly repaired." Nevertheless, the National Automobile Dealers Association, General Motors, Ford and Chrysler opposed the legislation.

It is at the value level that broader questions arise about the allocation of always scarce national resources. Competing for these resources are the military, poverty, space, housing, health, agricultural and other programs. For a brief period after the publishing of Ralph Nader's book (Nader, 1965), traffic safety had a relatively high priority value. With the media's usual search for new sensation, and the rise of perceived threats to existing institutions growing out of other social problems, traffic safety has slipped into oblivion. Functionally, pragmatically, and operationally, we do not value traffic safety very highly at this point. If the political decision were made today to provide safe and efficient ground transportation, and if the decision was accompanied by a realistic appropriation of funds, we could make significant inroads into the traffic safety problem within five to ten years, and probably eliminate the problem in fifteen or twenty years, principally by developing alternatives to the private vehicle. Short of severe and recurrent crises in transportation or crises arising out of its by-products, such as pollution, it is most likely that our present token approach will continue, with little change in the social cost, expressed in deaths.

I have described traffic safety as a social problem made up of a series of levels (see Figure 1), extending down into the roots of society. Crashes, deaths and injuries were placed at the symptom level. The symptoms were viewed as predictable products of a faulty man-machine system. Underlying the faulty transportation system, I described an inappropriate and ineffective management and legal system, only recently meliorated to a limited extent by the creation of the NHSB. Foundational to the whole problem, I concluded that our knowledge was insufficient to bring about a substantial change in the problem, given present constraints, and further, until there was a political and economic commitment to the value of human life and

Level	Content	
Symptom	Pre-crash—Crash—Post-crash Events	
System	Men—Machines—Environment	
"Management"	Laws, Institutions, Men	
Foundations	Knowledge	Values

FIGURE 1. *The Structure of the Traffic Safety Problem*

well-being instead of to short-range profits, convenience and a host of nonrational gratifications, the traffic safety problem would remain essentially unchanged in the foreseeable future.

Compared with other definitions of the problem, the concept of a *social problem* is more inclusive and realistic. This view subsumes quantifiable systems approaches but recognizes the extent to which nonrational and irrational considerations limit the use of such rational approaches to decision-making. The simplistic and ineffective emphasis on the driver that characterizes variants of the "nut behind the wheel approach" I have rejected in favor of a structural view of the problem that increases the number and type of opportunities for its melioration.

Comparing the Consequences of Alternative Safety Problem Definitions

The way a problem is defined and the assumptions underlying the definition have implications for the way relevant managements try to eliminate or control the problem, the nature of the legislation that is enacted and the type and content of research.

The "nut-behind-the-wheel" philosophy produced legislation aimed principally at controlling the driver, to the virtual neglect of the other components of the system. Administrative policy naturally followed suit, with an emphasis on enforcement and sanctions. Research also reflected this approach, trying to identify the characteristics that discriminated between good and deviant drivers. A great deal of effort went into studies based on the concepts of accident proneness, personality types, reaction time, attitudes, etc. Based on a limited definition of the problem, this research has had little or no pay-off. Psychiatrists, psychologists, teachers and parents find that modifying attitudes and personality is difficult, and often impossible, under the most ideal conditions. Can you imagine the resources necessary for a realistic attempt to modify the psychological make-up of millions of drivers?

The so-called "balanced approach"—education, enforcement, and engineering—resulted in a fragmented traffic safety strategy by state legislatures and agencies. Laws were not promulgated that encouraged the fit, or match, of the system components. Administrators dealt with the driver, the vehicle and the highway as if they were separate well-being instead of to short-range profits, convenience and a host of nonrational gratifications, the traffic safety problem would remain essentially unchanged in the foreseeable future.

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Research, under this orientation, is similarly fragmented. Engineers study their pavement material, traffic flow, signing, highway geometry, etc., without consulting with social or behavioral scientists to find out if the human beings in the system can read their signs or cope with the exit and entrance ramps or with the conflict situations that their engineering produces. I think that every city in the country has its impossible traffic configuration, known as its "cement mixer," "spaghetti bowl," "whirlpool," etc. Automobile manufacturers researched buyers' style preferences, but not their ability to survive the inevitable impacts in which their vehicles were predictably involved.

Systems approaches require a management interested in and capable of rational decision-making. Under this orientation management and research would work together to devise and test the models of the system and its parts. The problem of the transmission of research results to decision-makers would be reduced, with management actively seeking data to plug into their models. Using this approach there would also be a concern for the interrelationships between the parts of the system, a concern that would be evident in legislation. The effectiveness of proposed safety measures would be estimated through simulation techniques, and empirically through pilot studies, if possible.

The consequences of a systems definition for safety legislation, management and research appear to approach the ideal. There is an important drawback, however. Systems approaches assume a management striving towards rational decision making, with control over major components of the system and with a rational basis for predicting those influences over which they have no control. It is for this reason that systems approaches find their most ready and successful uses in the military, in hardware-type projects and in industrial management—environments characterized by high degrees of control and experience in prediction.

When systems technology is brought into public systems, immediately two obstacles arise. First, there is conflict as to the goals of the public systems; and second, those directly or indirectly responsible for the system operate under an overriding value of *power*, to protect and enlarge their power.

In contrast with the preceding approach, the view of traffic safety subsumed under a *social problem* definition takes into account the conflict of values that faces politically based managements. Under this approach, management is a political as well as a technological animal. The research possibilities here include making explicit the underlying value conflicts. Research does not concentrate on the personalities and attitudes solely of the driver, but emphasizes the decision-makers. What have been the attitudes and values of the managements of the "safety establishment" that for years dominated the national approach to traffic safety? At what level of the understanding of the problem are the legislators, the judiciary, the police and highway and traffic commissioners and engineers? How can their attitudes be modified? How can their knowledge be brought up to date? These are far more significant questions than the research aimed at modifying the individual driver alone.

The English experience with changed enforcement and alcohol testing (Ross, *et al.*, 1969) suggests the probable efficacy of this approach in reducing the role of alcohol in crashes in this country. If long-range experience bears out the initial success of their campaign, and if the required enforcement practices can be reconciled with our concern for civil liberties, then how can the relevant decision-makers be encouraged or persuaded to take the leadership role that would be necessary for the acceptance by the public of such stringent enforcement? For years, research has subtly placed the blame for the failures of traffic safety on the driver. A potentially more effective approach would emphasize the role of management (legislators, highway commissioners, etc.) in conceiving, designing, constructing and maintaining a system in closer accord with user characteristics and capabilities.

Many millions of dollars are spent by motor vehicle manufacturers on advertisements encouraging a nonrational view of highway transportation. What is the responsibility of highway management in promulgating a rational approach—or still better—in providing a man-machine system that makes the rationality of the users irrelevant to their safety?

I have at times driven on the highway between Raleigh and Chapel Hill in a rented car. Driving in an unfamiliar car is always an uncertain experience where clearances are limited or highway geometry unfamiliar. It has been my impression that the Raleigh-Chapel Hill highway is the narrowest on which I have ever driven. Given such a highway I would expect frequent single car run-off-the-road incidents, side swipes and head-on collisions. With the help of Forrest Council and the North Carolina Department of Highways, I learned that on this 23.8 mile road, that more than 33 percent of the crashes involve a single vehicle running off the road and more than 58 percent involve two or more vehicles. Nationally, approximately 33 percent of the rural crashes involved run-off-the-road incidents and 43 percent are between two or more motor vehicles. The road literally invites vehicle-to-vehicle crashes.

Further, I learned that during 1969, there was a crash every 2.3 days, an injury every 8 days and a fatality every six months. This represents a slightly worse record than for the other roads of the same type in the state.

The National Safety Council reports that North Carolina is among the worst 11 or 12 states in its mileage rate (7.1 vs. a national average of 5.47), vehicle registration rate (7.3 vs. 5.41) and population rate (3.6 per 10,000 vs. 2.8).

In part, North Carolina's record can be accounted for by the rural nature of much of the state. However, of the various definitions of the problem, which holds the most promise?

Shall we simply persuade drivers to "drive safely" since "the life they save may be their own"? Shall we study their personalities? Should we increase the enforcement on the Raleigh-Chapel Hill Highway? Perhaps this would help, but given present budgets, would the diversion of police resources to the one road simply aggravate the problem elsewhere? Would a system's study of the road help by more effectively allocating the resources presently available?

Would it help to study the knowledge and values of a population and their public servants, that calmly accept as the price of travel between two civilized cities, one death every six months, an injury every eight days and a crash every 2.3 days?

Would it help to devise, make available and *encourage* the use of alternate transportation modes?

What decision processes have been involved in the apparent neglect of the highway? What values were considered in the failure to broaden it? Who are the decision-makers and what pressures do they perceive acting on them? What are the attitudes, values and personality characteristics of these decision-makers? What is their definition of the traffic safety problem? How aware are they of recent research findings? How do they learn about research? How can their behavior be modified in ways that will enhance traffic safety?

Viewing traffic safety as a social problem makes it clear that action or research limited to only one level of the problem may be insufficient. Although cars are being made more crashworthy, roadsides more forgiving, emergency medical care more effective—all measures designed to deal with the symptom level—speeds continue to increase two miles per hour per year (U.S. Bureau of Public Roads), with the promise that if left uncontrolled by the management level, the increases could eventually negate many of the benefits derived from the changes in the vehicle, roadside configurations and emergency services. The management decisions about speed rest in part on the value base and on the knowledge of the consequences of increased speed for the system. How many lives and injuries outweigh the economic benefits, convenience and psychological gratifications of increased speeds? It is unlikely that the question of speed and safety can be considered realistically without taking into account the implications of this question at all levels of the problem.

SUMMARY AND CONCLUSION

In conclusion, I have suggested that the definition of a problem influences the objectives and content of relevant legislation, management and research. I compared the consequences of defining traffic safety as the problem of "the nut behind the wheel," as a problem of isolated components, requiring a "balanced" approach, as a "systems problem" and finally as a "social problem." I concluded that unless we see traffic safety as centered on the need to provide a match between man and the rest of the system by management and legislation resting on an appropriate knowledge and value base, and unless we take into account the political, psychological and economic motivations of the *key decision-makers,* our attempts at controlling the problem will be largely ineffective.

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DISCUSSION

Elmer R. Oettinger

Dr. Oettinger's credentials include training and experience in the dramatic arts, teaching in the academic world, and coming to grips with social problems in the political realm. He holds an M.A. in dramatic arts, a degree in law, and a Ph.D. in English, all from the University of North Carolina at Chapel Hill. He has also pursued graduate studies in playwriting, scenario writing, and motion pictures at Columbia University.

Currently, Dr. Oettinger is Assistant Director of the Institute of Government and Associate Professor of Public Law and Government at the University of North Carolina at Chapel Hill. He also is editor of Popular Government, a magazine for governmental officials at all levels in North Carolina. Dr. Oettinger continues to make use of his many talents, applying his dramatic skills to the problems of economic development of the state. He recently produced a film about the Piedmont Crescent that won acclaim in New York. His major efforts at the Institute of Government are in the field of motor vehicles and criminal justice.

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LET'S DARE TO BE SAFE!

I stand before you a motorist who has had a mishap only five days ago. I struck a dog and killed him. I struck a beautiful curly little French poodle, and he died almost instantly. I struck him on a shady, quiet, urban street. I struck him without a chance to avoid him, for he ran suddenly from the bushes beside the road on to the street directly under my wheels. The fact that the accident was unavoidable in no way appeases my sense of frustration and sorrow. But it occurs to me that I could have struck a small child in much the same way—without fault, and with much greater and more profound distress and sorrow. Of course it isn't enough to be aware of the continuing nature of the factors of human and mechanical failure in a given situation and even of a sort of inexorable fate which can cause accidents. But the factors are there, and no amount of awareness of the larger picture and of strategies which have a chance to be effective in promoting traffic safety can erase them. I would at the outset, then, face the unresolvable, but perhaps diminishable, factors of chance and human imperfection.

Having said that, let me express a personal sense of appreciation of the breadth and depth of Dr. Blumenthal's analysis of our safety problem. I share his concern for our isolated and compartmentalized approaches to the complex inter-relationships which make up the overall problem. Nor am I sure that he or I or all of us here together has yet considered or could, in the time and circumstances, consider all of the factors, the knowledge, and the values which enter into the traffic safety problem. The mismatch to which he refers between human capabilities and system demands applies in another sense to the human understanding of the relationship between the tragic toll on our streets and public highways and the political, economic, and philosophic bases of controlling thought and action in our society today.

In a very recent column, James Reston wrote: "The question now is whether the oldest idea in American politics—the idea of a citizen's lobby, fighting for the interest of the majority—can be organized in a modern urban society." He concludes: "But they (citizens) have to organize in the general interest or they will be overwhelmed by the organized special interests." Perhaps the best illustration of that point for our purposes lies in the fact that the campaign to require automobile makers to make safer cars, initiated so powerfully, skillfully, and effectively by Ralph Nader, seems to have bogged down badly in the halls of Congress and Department of Transportation, due apparently to the terrifically strong counter pressures from the automakers themselves. The public response, which had strength and bite under the first encouragement of Nader's book and subsequent campaign, lacked a sufficiently broad base of strength and organization to exert continued pressure where pressure is most needed. And that seems to me to be an ultimate consideration and barrier to achievement in traffic safety of any of the goals proposed so eloquently by Dr. Blumenthal.

If we must first know the depth, extent, and breadth of our problems and then formulate our coordinated campaign to reach carefully analyzed goals, we have scarcely begun to fight. For at this stage we do not even have the basic tools. And the foremost of those tools is human resources. We have not even begun to win the battle for the minds of millions of motorists who logically have everything to gain from understanding the nature of the problem and their personal and family stakes in it.

Specific applications of Dr. Blumenthal's thesis to North Carolina are obvious. They can be illustrated over and over again. We have used the "sloganeering approach" to traffic safety, frightening drivers with echoes of "And Sudden Death," displaying wrecked vehicles on courthouse lawns, backed by high-rise thermometers recording in a rising red line the incidence of accidents and supported by dire warnings in newspapers and on radio and television. Despite the findings by Dr. Mendelssohn at the University of Denver and others that most drivers do not associate themselves with scare warnings but tend to relate them to others, we only recently have come around to presenting radio and television public service announcements with which the driving public hopefully can identify.

Our highways contain the "booby traps" to which Dr. Blumenthal refers and too often they reflect "neglect of the drivers' capabilities in the design and signing of the interstate system." It is easy to point out exit ramps in too close proximity to entrance ramps. We still have highways and bridges that are too narrow and roads that are poorly banked. The asphalt paving of our secondary roads requires frequent repair and not infrequently is rutty to the point of driver hazard. Even our concrete highway system is subject to frequent doses of tar and overpaving with black-top. Some roads are slick when wet. Dual-lane interstate systems turn abruptly into two lane roads with two-way traffic. Recent crashes include one two-vehicle collison just after the point where a north-south interstate suddenly becomes two-lane and two-way. Ten persons were killed at that crash. The lack of adequate siding on most of our two-lane roads provide invitation to disaster. A driver with a flat tire or motor trouble frequently has insufficient room to pull his vehicle off the road and attempt repairs—or even to wait safely. As a consequence, our drivers not only have to make decisions faster than may be humanly possible; sometimes their choices are too limited or nonexistent.

The requirements of driver compensation and defensive driving become unusually important under such circumstances. If we have no power over the design of cars, we do have substantial power over who drives on the highway and the kinds of roads to be traveled on. If we lack the power (or the desire) to prevent huge trucks from using and damaging our highways, we have the power to set some of the conditions under which all vehicles, including trucks, may use our road systems. The question of management coordination remains a difficult one in any public area in which executive, legislative and judicial decisions all are involved. The very nature and complexity of such problems affect our sense of values upon which, in turn, depend the amount of progress in traffic safety during any time continuum.

Several years ago when highway safety accident and fatality rates continued to rise, the Governor made a statement on traffic safety in which he, in effect, wrote off the possibility of change for the better. He felt that all our programs had been failures and that there was no indication that any foreseeable program would work to effectively bring about and maintain improvement in safety records and standards.

Recently, working with the Commission now studying auto liability rates in North Carolina, I have had an opportunity to see films in which various automobiles were crashed into barriers and into other vehicles at rates of five and ten miles per hour. The results confirmed the high damage figures cited by Dr. Blumenthal. The visual impact of easily crushed bumpers and the crunching of torn metal in such low speed collisions was almost as great in damage to human preconceptions as to the vehicles themselves. The familiar claim that a more yielding construction of vehicles helps protect human life even as it makes the auto more vulnerable raises questions as to why both vehicle design and human safety cannot be served in better ways. Witnesses have told us that they can be.

Further, the very complicated problems relating to auto liability insurance itself may create hazards which should be added to the complex of considerations required overall for any upgraded traffic safety programs. For example, the State of North Carolina apparently has some 23 percent of its motorists—almost one out of every four—on assigned risk. No other state comes close to that infamous figure. Most have no more than one or two percent of its drivers on assigned risk. Evidence has been presented that a number of the persons now on assigned risk should not be there, some of them apparently having had no accidents, no violations, no driver point deductions. One witness told the Auto Liability Insurance Commission recently of a young friend who wound up in prison as a result of his inability to pay his auto insurance premium. This young man, we were told, was required to drive to and from work. His wife was eight months pregnant. In a desperate attempt to find funds to pay his premium, he turned to theft. He wound up in prison and his wife and infant child on public welfare.

I do not wish to pre-empt the functions of the Auto Liability Insurance Commission which has really only begun its study and presumably will have to decide upon recommendations to the Governor and the next General Assembly. It is a tough and complex study in itself, and at this point I do not presume to know the answers. I am confident that the Commission will try to come up with important and fresh proposals in an area of public concern relevant to traffic safety.

The question of the youthful driver, of course, is always with us. It is ironic that the age group which has the best reflexes should have the worst driving record. Certainly the figures raise questions as to the judgment of those drivers between the ages of 16 and 25, questions which may very well apply to the judgment of persons that age who wish to decide what is best for society on other fronts. It is quite true as Dr. Blumenthal points out, that even our "balanced approach" to traffic safety has resulted in fragmented traffic safety strategy. It is true that laws which have been promulgated have not always "encouraged the fit or match of the system components." Our own General Assembly passed a "little" statute which prohibited giving parallel parking tests to persons over sixty. The net result of that gem has been to stop the giving of parallel parking tests (as a part of the driver license examination test) to any driver of North Carolina. For the Driver License Division felt that if grandma and grandpa could not be required to take such a test, it would seem rather foolish to require it of papa, mama, and junior. Similarly, other legislation relating to driving, vehicle safety, and other aspects of highway safety also may be considered without sufficient information to relate the specific proposal to the whole spectrum of the law or to the overall requirements of traffic safety. Pressures and demands of other legislation do not always permit a rounded approach by the individual legislator or by a legislative committee.

A major source of trouble is the lack of sufficient understanding of any new kind of approach, such as the systems approach to traffic safety. Obviously, sufficient updated research and hard evidence are difficult to come by. In addition, there is the ever present human factor. All who have responsibility in the motor vehicle process—department officials, law enforcement officers, legislators, administrators, the driving public—have individual attitudes molded by different backgrounds, self-images and self-interests, and different senses of public responsibility.

Management may be interested in decision making. It may even be capable of rational decision making, although that capacity varies from management to management. But whether management and research people can work together objectively to devise and test "models of the system and its parts" remains for proof. And the transmission of research results to such decision makers as public officials will continue to meet barriers. To begin with, fresh ideas in controversial areas always encounter intense pressures from narrowly oriented interests. Add to this a want of sufficient comprehension, understanding, and interest from large segments of the very public which stands to benefit most from these ideas. The result often is the inevitable bedevilment of the efforts of dedicated public officials and informed citizens.

So many of the segments of the system involve items which are all important in determining who drives on the highway, what kind of cars they drive, and what sort of law enforcement we have. For one small illustration of the complexity of the problem as to *who drives,* consider the standards of grading our driver license test. Any motorist seeking license renewal and able to pass an eye test has simply to answer 14 of 20 questions relating to traffic safety. In other words, we have found it convenient to pick the arbitrary standard of 70 percent right answers with which persons are familiar as representing a passing grade in the public schools to be a passing grade for our driver license test. Obviously, it is possible that drivers who miss six questions may not know all they need to know to drive safely on our highways. Yet the 70 percenters pass and drive daily in all parts of the state.

Both driving points and insurance points, two different kinds of points, affect who drives and under what circumstances in North

Carolina. As I have indicated, about one in four drivers in our State is on assigned risk. But not all of them have had automobile accidents or given other tangible evidence that they are or may be risky drivers. We are informed that some are on assigned risk simply because they are newly moved into the community or are reported as having had marital or family troubles. Drivers who have to borrow to finance car insurance often wind up on assigned risk. The older driver often is required to take a thorough physical examination and risk the results in order to have auto insurance renewed. The upshot is that a considerable number of auto liability insurance policies appear to be placed in the assigned risk category arbitrarily. The resulting misunderstanding, confusion, and mistrust of the system complicates the problem of persuading the public to support valid programs. Public objection to any facet of an auto-related program which is deemed to contain inequities and cause unhappiness tends to lap over into related areas. Public antipathy to the handling of auto insurance does not encourage public support for related programs in traffic safety.

What about a systems approach? No systems approach can disregard the human factors in traffic safety. Human attitudes, ultimately, will determine the success or failure of any approach. More and more it is evident that many people have come to regard a drivers license as a right rather than a privilege. These drivers look upon transportation to and from work as a necessity. Whatever their guilt of serious driver or owner violations, they regard the taking away of their drivers' license or vehicle license as an affront and a denial of an inalienable and intensely personal right.

It appears that a vast job of re-educating of human beings on basic safety law needs to be undertaken. Yet the times themselves affect the possibilities here. Dissatisfaction and revolt are rampant. Public attitudes, especially those of the young, differ radically from earlier eras. Whether this factor is transitional remains to be seen. As always, some synthesis will come out of the current discontent. The important thing, it seems to me, is that clear, humane values and directions not be sacrificed to the often sightless negativism of the destructive and unknowing. Too many today have neither the knowledge or experience nor, oftimes, the desire to find constructive solutions. It is all very well to say that we have failed to solve our problems in the past; that is obvious, but it is another thing altogether to come up with workable answers for the future that all elements of the public can be prevailed upon to understand, affirm, and abide.

Again, it is imperative that we consider the broadest ramifications of the problems of auto transportation itself. We must join in general recognition of the danger of the gas-and-oil-propelled motor vehicle to our environment. The threat of auto-truck pollution may be no less grave than that of death by collision on our highways. The implications which underlie the search for better propulsion agents include the possibility of fundamental changes in the nature and workings of motor vehicles. The electric car, the monorail and those vehicles which move on a cushion of air are harbingers of change. So are proposed new safety devices. Any change in vehicle construction or adjuncts will work profound effects upon our safety problems and requirements. Since life is dynamic and predicated on change, we must expect change. And change always brings new problems even as it provides solutions to some problems we now have. If this is looking ahead to the intangible and the indefinite, both in time and nature, so be it. We need to look ahead. But we also need to push for more bold and clear visions and for some certainty of their practical applications before we can match them to this huge complex of traffic safety. A systems approach may lead to progress; it cannot obscure the urgent need to meet present and foreseeable problems with a continuum of thought and action.

We face incalculable problems in striving to obtain a management approach attuned to appropriate and essential standards of value. Unsafe vehicle design, unsafe manufacture, unsafe driving, unsafe highways, and inadequate traffic laws are joined in a macabre dance of needless destruction and death. The role of alcohol in a majority of crashes provides one cogent illustration of present fallacies in human attitudes. As long as many citizens, including judges and jurors appear to feel "There but for the grace of God go I," it will be difficult to bring consistently effective legal action against those charged with drunk driving. Yet the figures indicate that more than half the drivers of those involved in automobile accidents on our highways have been drinking. And clearly the human body has small tolerance for drink as applied to driving skill. More flexibility in sentencing could prove beneficial to enforcement of the law against the drinking driver.

The computer is proving valuable assistance to law enforcement in research and practice. But we must not expect too much of computer help. No machine, no system or systems, are worth more than the value of the information fed into them.

Thus, while a rational application of the system approach, a "matching of man and the system environment by management and legislation resting on an appropriate knowledge and value base," and a careful consideration of "the political, psychological, and economic motivations of the key decision makers" do offer fresh directions and ground for hope that new impetus will be given to improving vehicles, highways, and driver safety; to expect miracles even from so logical and modern an approach is to promote new illusion. We still are groping at promising beginnings. The dimensions of the challenge are becoming clearer; we still face the crossroads. And we will find any new directions difficult to take so long as so many intangibles remain to be solved.

Matthew Arnold once wrote that Sophocles saw things steadily and saw them whole. It is difficult if not impossible for men to do that. Rather, Alexander Pope's warning seems more applicable. He wrote: "A little knowledge is a dangerous thing." And in our time T. H. Huxley observed: "If a little knowledge is dangerous who among us knows so much as to be out of danger."

We remain in danger in traffic safety. A systems approach sets a challenge and a direction. Its effectiveness hinges upon its equation with human awareness and understanding and its ability to cope with human frailties that so long have plagued safety efforts.

The first steps are to muster our forces in research, experiment, and planning. The next are to combine and coordinate our efforts to win minds and hearts to a course of action offering breadth, depth, and promise to men and systems. Only when such a coordinated approach is underway will we be able to savor the meaning of "save" in safety.

Section II

Highway Safety Myths

David Solomon

Discussant

B. J. Campbell

DAVID SOLOMON

Mr. Solomon is a highway research engineer with the Traffic Systems Division of the Bureau of Public Roads, Federal Highway Administration, U.S. Department of Transportation. He received his training in civil engineering and has been in highway research for almost two decades.

He has published papers concerned with the association between highway crashes and speed, traffic density, traffic signals, sign visibility, and other factors. Other publications examine government programs in highway safety.

A consultant for a number of government agencies, Mr. Solomon's work has been formally recognized by the Institute of Traffic Engineers and the Department of Commerce.

HIGHWAY SAFETY MYTHS

By David Solomon

During the past seven decades, highway transportation has played an increasingly important role in the national life of the United States. It has literally united the nation because it has provided the average man with a flexible, low cost means of moving himself, his family, and his goods, from place to place. However, some undesirable side effects have accompanied this personal transportation system, of which the most important is a very large number of highway accidents, injuries, and deaths.

Figure 1 shows the trend since 1920 in deaths and the death rate for motor vehicle accidents on highways in the United States (The Federal Role in Highway Safety, 1959). The death rate declined rapidly in the early years of highway transport, but since 1960 it has remained nearly constant with about 5 deaths for each 100 million vehicle-miles of travel. Because highway travel has increased about four percent each year during this period, highway deaths have increased substantially and now exceed 55,000 each year. Trend data on accidents and injuries are less reliable, but these too have increased over the decades.

Approximately four million people are injured yearly on the nation's highways, to an extent requiring medical attention or some activity restriction (Accident Facts, 1969). The total number of accidents that are reported is approximately 15 million each year, and additional millions of minor accidents are not reported. Total accident costs approximate 15 billion dollars annually.

This staggering toll of deaths, injuries, and accidents has generated strong desires to "do something" about an horrendous national problem. Partly as a result of this, a large number of theories have gradually evolved for reducing highway accidents and the suffering and economic losses that result. Although data are available to show that many of these theories are myths or half-truths, they persist nevertheless. Their persistence is particularly unfortunate because remedial measures based on such myths push into the background programs that might really help to reduce the toll of highway accidents.

The purpose of this paper, therefore, is to debunk a number of highway safety myths; to describe some approaches that have been

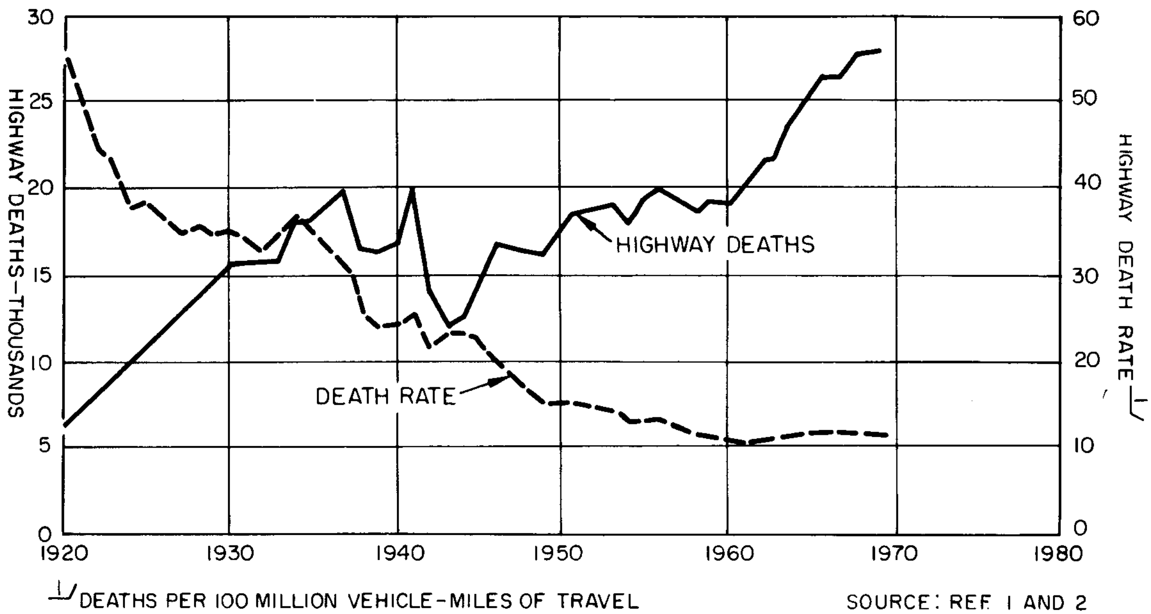


FIGURE 1. *Highway Deaths and Highway Death Rates in the United States*

usefully employed to obtain highway safety; and to suggest a highway safety program for reducing substantially the incidence and severity of motor vehicle accidents. The suggested highway safety program gives priority to those techniques that have been shown to be effective and emphasizes the need for research, development, test and evaluation, particularly for unproven projects. In short, an unbalanced highway safety program is needed.

A MYRIAD OF MYTHS AND SLOGANS

Dozens of myths, half-truths, and slogans have built up about highway safety. Time will permit discussion of only the few that seem to have engendered the greatest following and have therefore been most effective in diverting effort from truly useful highway safety programs. Some of these myths recur from time to time in slightly different form but the essentials tend to remain the same. Data are generally available to debunk these myths, but in some cases, although the preponderance of the evidence indicates that the belief has little substance, additional evaluation studies are desirable to provide conclusive evidence or to delineate those situations where the belief may have some validity.

'The Nut Behind the Wheel'

Over the years, many traffic safety programs have been built on the premise that a small group of identifiable drivers is responsible for a large portion of all traffic accidents. At least two studies have shown that this is not the case.

One of these studies was summarized by former Federal Highway Administrator Rex M. Whitton in 1965 when he stated that research data involving 150,000 drivers showed that it is wrong to assume that a small group of careless or dangerous drivers are largely responsible for most highway accidents (News release, Bureau of Public Roads, April 5, 1965). A Bureau of Public Roads analysis showed that 90 percent of drivers involved in an accident in one year would not be involved in the following year and that the drivers involved in all accidents in one year would be involved in only 11.5 percent of all accidents the following year.

The upper half of Table 1 summarizes the results of this study, which employed data obtained from California (Coppin, McBride, and

TABLE 1. *Reported Accidents by Groups of Drivers in Two Successive Time Periods*

California Data, one-year

time periods: 1962, 1963

Number of Accidents This Year	Percent of Drivers	Percent of Accidents This Year	Percent of Accidents Next Year	Zero Accidents Next Year Percent
0 or more	100.0	100.0	100.0	94
1 or more	6.7	100.0	11.5	90
2 or more	0.5	13.9	1.1	87
3 or more	.04	2.0	.1	85

Connecticut Data, three-year

time periods: 1931-33, 1934-36

Number of Accidents First 3 Years	Percent of Drivers	Percent of Accidents First 3 Years	Percent of Accidents Second 3 Years	Zero Accidents Second 3 Years
0 or more	100.0	100.0	100.0	90
1 or more	11.1	100.0	20.7	82
2 or more	1.3	22.7	3.7	76
3 or more	.14	3.5	.7	66

Source: Refs. 2, 12, 15

Peck, 1964). The findings are based on only those accidents which were reported to public authorities, but there is no reason to believe that the conclusion would be any different if all accidents were included. The table shows that in any one year 0.5 percent of the drivers have two or more reported accidents and that they account for 13.9 percent of all accidents. If these drivers were prohibited from driving next year, accidents would be reduced only 1.1 percent because this is the number of accidents they would have next year. The reason is that accident-involved drivers are distributed on an approximately random basis, and nearly all "accident repeaters" in any one year are so classified by chance alone. Thus, if nothing is done, nearly all of these drivers will not be accident repeaters (two or more accidents) next year. In fact, 87 percent of these drivers will not have even one reportable accident next year.

If every driver had the same chance of being involved in an accident, it would be expected that 0.5 percent of any group of drivers (but in this case "accident repeaters") would have 0.5 percent of the accidents. The fact that they have 1.1 percent of the accidents in the second year can be explained by these factors: (1) relative driving mileage and hence exposure to accidents may be greater for this group of drivers, and (2) age and sex differences affect accident involvement and, as a group, younger drivers are more likely to be involved in accidents. These two factors could easily account for nearly all of the variation between 0.5 percent and 1.1 percent. Analyses for drivers who had 3 or more accidents are also shown in Table 1.

An earlier study based on data taken in Connecticut in the mid 30's was best analyzed by T. W. Forbes in 1939. These data, recast into a format similar to the more recent California data to permit easy comparison, are shown in the lower half of Table 1. The general trends and conclusions are quite similar to the upper half of Table 1. The somewhat greater tendency for accident-involved drivers to repeat in subsequent three-year time periods can almost certainly be attributed to the comparisons being between two three-year periods rather than between two one-year periods. But even considering two three-year periods, the 1.3 percent of "repeat" drivers who, with two or more accidents accounted for 22.7 percent of the accidents in the first three years, were responsible for only 3.7 percent during the second three years.

Clearly, therefore, the concept of the "nut behind the wheel"—that is, of certain identifiable drivers being responsible for a large share of all accidents—is not valid. Over 99 percent of all drivers do very well indeed as measured by their general lack of repeater accidents. The remaining drivers cannot be readily identified and even if they could, removing them from behind the wheel would have only a trivial effect on accidents. Therefore, efforts must be directed at helping *all* drivers, and not at penalizing a few who are thought to be hazard-producing.

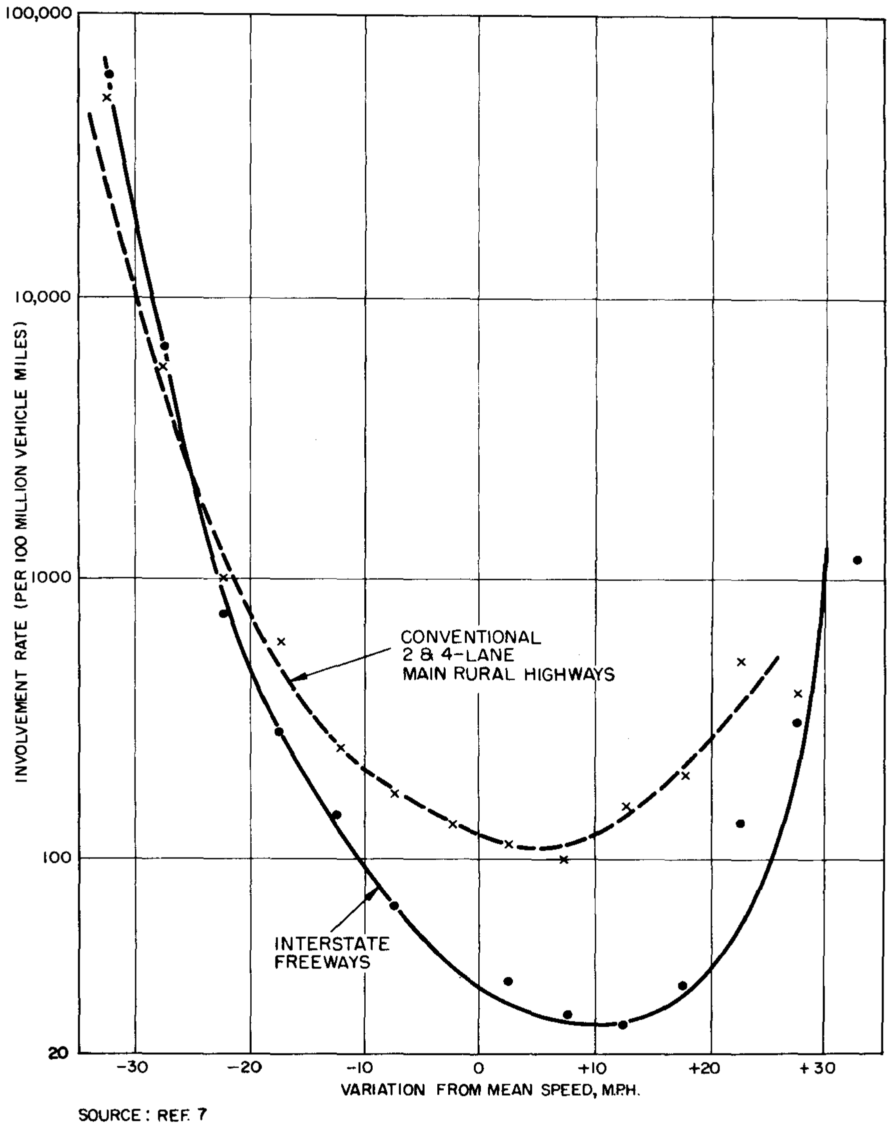
Those programs which attempt to "select" a small proportion of drivers as "hazardous" or "accident prone" are doomed to failure. In military or commercial truck operations, such procedures may be possible, but 70, 80, or 90 percent of potential drivers must be rejected (Uhlaner and Drucker, 1965) to obtain an accident rate reduction of a few percentage points. Such procedures are obviously not feasible for 100 million civilian drivers.

'Slow Down and Live'

This slogan and its corollary, "Speed Kills," have been used in many propaganda campaigns and are over-simplified. Although the severity of an accident increases with speed, particularly when the travel speed before the accident exceeds 60 mph, the chance of being involved in the accident follows a U-shaped distribution (Solomon, 1964). The chance of being involved in an accident, at least for two-lane and four-lane main rural highways and freeways, is lowest at about the average speed of all traffic on the highway and increases at speeds above and below the average speed, as shown in Figure 2. The involvement rate shown is the number of drivers (or vehicles) involved in accidents per 100 million vehicle miles of travel.

The probability of being involved in an accident, shown in Figure 2, combined with the severity of the accident in terms of persons injured per hundred accidents, results in calculated injury rates. Figure 3 shows the results of such calculations for two-lane and four-lane main rural highways. It is evident that the lowest injury rate is at about the average speed on these study sections, where the average travel speed was approximately 52 mph.

Data for fatalities are sparse, but there is some indication that the fatality rate is also lowest at about the average speed of all traffic,



SOURCE: REF. 7

FIGURE 2. *Accident Involvement Rate By Variation From Mean Speed on Study Units*

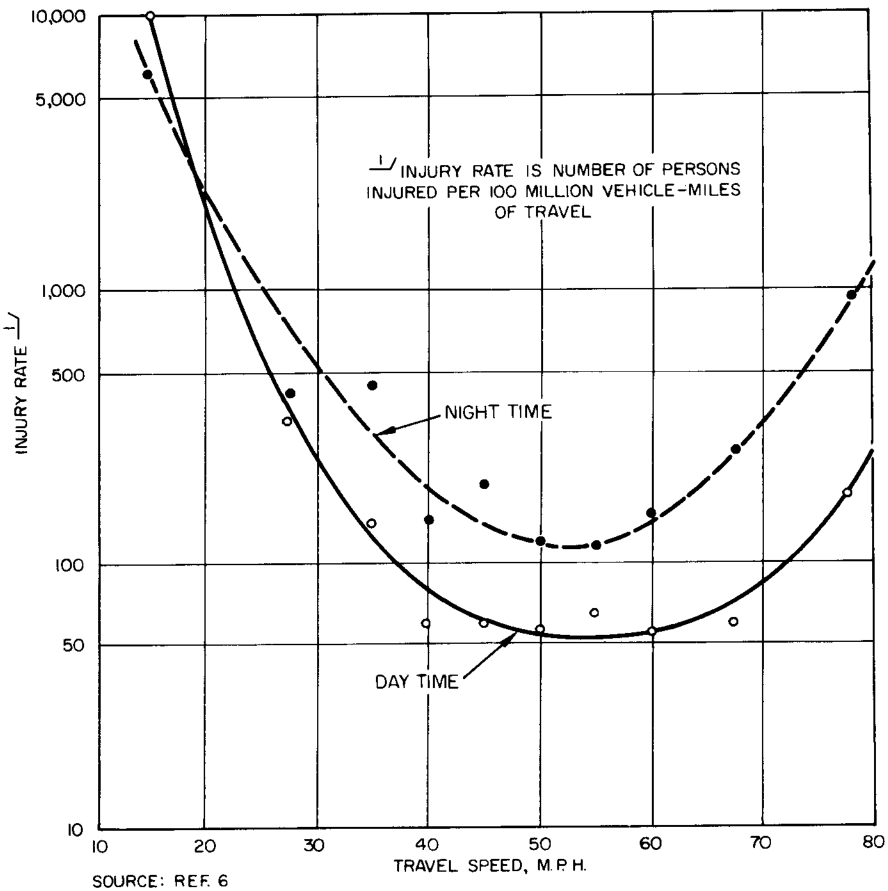


FIGURE 3. *Injury Rate By Travel Speed, Day and Night*

and tends to increase at both very low and very high speeds, as shown by the limited data in Table 2. Thus there is some validity to the statement, "slow down and live," which might be amended: "don't go too slowly." More useful is the recognition that the safest speed is close to the average speed of all traffic for any specific section of highway. Hence, rather than exhort drivers merely to slow down, more of a safety benefit may come from whatever can be done to facilitate driving at about the average speed without too much variance.

Examples of procedures for minimizing speed differences include: (1) Low weight-horsepower ratios for trucks, (2) climbing lanes for slow moving vehicles, (3) flat grades where feasible, (4) quick removal of vehicles involved in collisions, (5) quick repair and fuel services to stranded vehicles, particularly on freeways, (6) ramp metering and

TABLE 2. *Fatality Rates on Two-Lane and Four-Lane Main Rural Highways in the United States.*

<table>
<tr><th rowspan="3">Speed MPH</th><th colspan="4">Persons Killed</th></tr>
<tr><th colspan="2">Day</th><th colspan="2">Night</th></tr>
<tr><th>No.</th><th>Rate*</th><th>No.</th><th>Rate*</th></tr>
<tr><td>22 or less</td><td>17</td><td>621</td><td rowspan="2">21</td><td rowspan="2">15</td></tr>
<tr><td>23-42</td><td rowspan="2">12</td><td>2</td></tr>
<tr><td>43-47</td><td></td><td>13</td><td>10</td></tr>
<tr><td>48-52</td><td>24</td><td>3</td><td>29</td><td>11</td></tr>
<tr><td>53-57</td><td>17</td><td>3</td><td rowspan="2">23</td><td rowspan="2">9</td></tr>
<tr><td>58-62</td><td>17</td><td>4</td></tr>
<tr><td>63-72</td><td>15</td><td>5</td><td>21</td><td>32</td></tr>
<tr><td>73 or more</td><td>12</td><td>31</td><td>25</td><td>294</td></tr>
</table>

* Rate is number of persons killed per 100 million vehicle-miles of travel.

Source: Ref. 28

ramp merging systems, (7) passing aid systems to prevent build-up of slow moving platoons on two-lane rural highways, (8) use of flashing beacons rather than stop-and-go signals wherever possible to minimize stopping. Where it is not feasible to minimize speed differences, techniques can be developed to warn drivers of slow moving or stopped vehicles ahead.

'High Horsepower Cars are Dangerous'

It has often been suggested that the "horsepower race" is responsible for degraded safety. There is no evidence to support the assertion. Indeed, there is some evidence that very low horsepower cars are involved in a greater proportion of accidents, at least on main rural highways. One study shows (Solomon, 1964) that passenger cars with the lowest horesepower grouping—110 h.p. or lower—had an accident involvement rate nearly twice that of any of the five higher horsepower groupings. Moreover, it was true regardless of sex and age of driver, speed, or several other variables studied.

As expected, there was an indication that the findings were related to the relatively poor acceleration capability at highway speeds of cars having low horsepower. This finding is not surprising if one realizes that acceleration capability is important for passing on two-lane rural highways, for accelerating to highway speeds after entering the highway from an intersection or driveway, and for other traffic situations.

'New Highways Provide Permanent Safety'

As will be discussed later, freeways provide permanent safety, but this is not necessarily true for conventional types of highways. In fact, there is a clear indication that new highways which lack control of access, thus permitting construction of increasing numbers of business driveways and at-grade intersections provide less and less safety as they become older and permit more access.

When conventional highways are constructed on new rights-of-way, initially there are few commercial driveways and the safety record is good. As the highways get older, the traffic volume builds up, roadside businesses develop, more and more commercial driveways are cut, and the accident rate gradually increases.

For example (Cirillo *et al.*, 1969), on two-lane rural highways with average daily traffic of about 8,000 vehicles, increasing the number of at-grade intersections per mile and the number of roadside business driveways per mile one hundredfold, produced an increase in the accident rate of approximately 14 times as shown below:

Intersections Per Mile	Businesses Per Mile	Accident Rate*
.2	1.0	126
2.0	10.0	170
20.0	100.0	1718

* Accident Rate is number of accidents per 100 million vehicle-miles of travel.

This tabulation demonstrates the importance of maintaining control of access when either two-lane or multilane highways are built on new locations. Increased numbers of either intersections or driveways alone will also increase the accident rate. Intersections should be restricted to those essential for the highway, and the right of access from abutting businesses should be severely limited. Well-planned shopping centers and industrial parks are desirable because they provide indirect access to a highway from any businesses utilizing only a few principal driveway entrances to the highway.

'If You Drive, Don't Drink'

This slogan avoids the question: "How much may I drink and drive with reasonable safety?" Figure 4 summarizes the results of four studies that investigated both accident-involved drivers and a sample of normal drivers who served as controls. The proportions of both accident-involved drivers and normal drivers with various blood alcohol concentrations were computed and from these percentages the four curves shown were drawn relating the chance of accident involvement to blood alcohol concentration. Figure 5 combines the four studies into a single curve that is plotted on a linear rather than a semi-log scale in order to permit a better visual comparison. It is seen that a

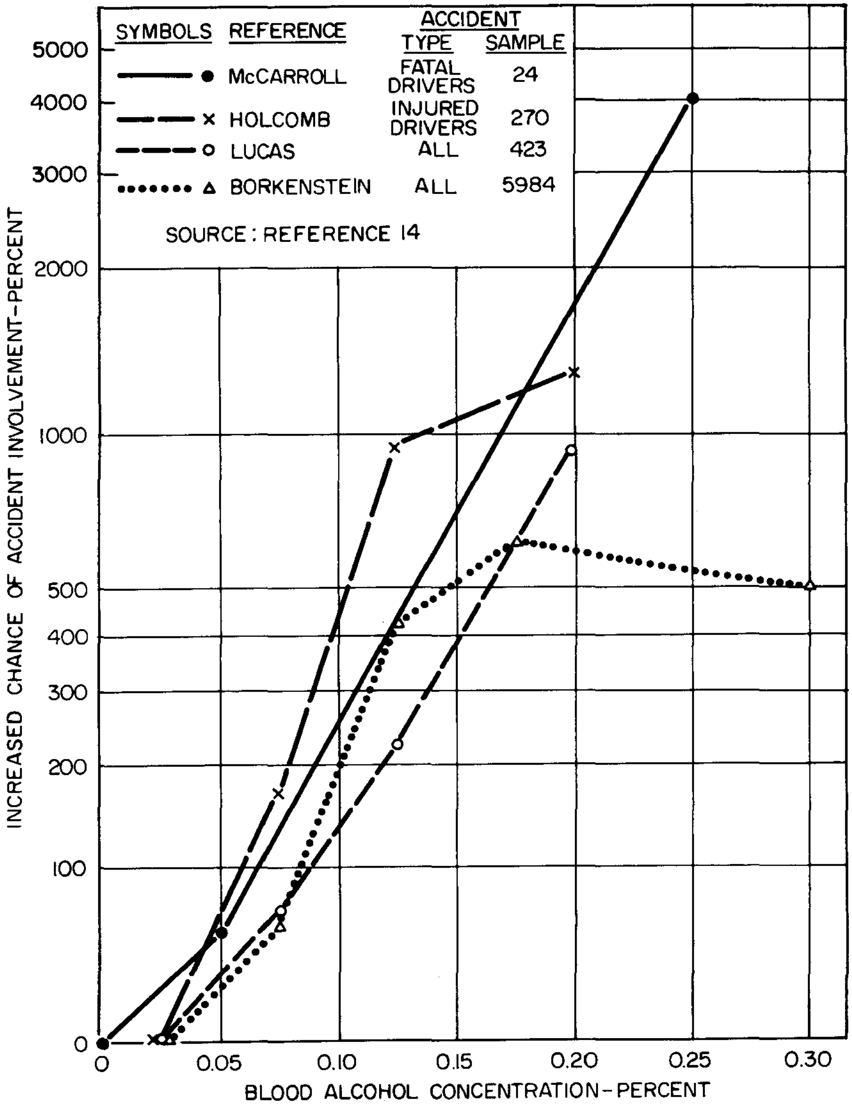


FIGURE 4. *Relation Between Blood Alcohol Concentration and Accident Involvement*

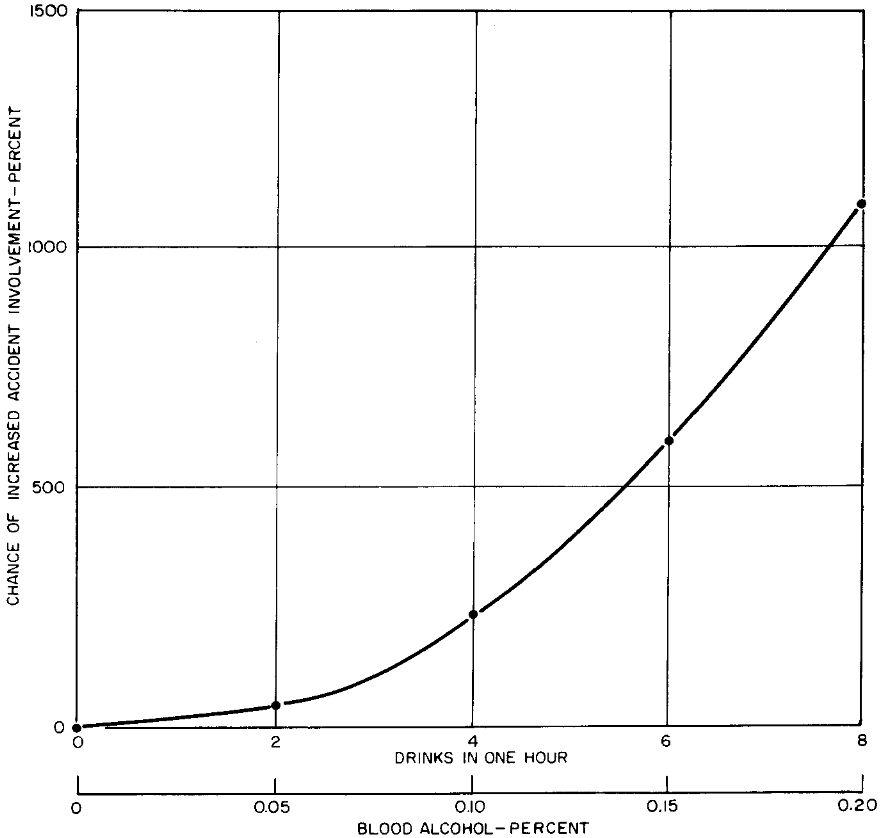


FIGURE 5. *Relation Between Drinks in One Hour, Blood Alcohol Concentration and Chance of Accident Involvement*

blood alcohol level of .05 percent increases the chance of accident involvement about 40 percent compared to a zero level of blood alcohol. Typically, this level of blood alcohol is achieved by a person weighing about 180 pounds who drinks two 1½ ounce shots of 90 proof alcohol or two 12-ounce cans of beer during a one-hour period. With four drinks or four cans of beer, the chance of accident involvement is increased 200 percent and a total of six drinks or six cans of beer increases the chance of involvement about 600 percent, as shown in Figure 5.

Clearly, therefore, alcohol is an important factor in highway safety but only when consumed in moderate and excessive quantities. Very light social drinking increases the probability of accident only slightly compared to heavy drinking.

If advice is needed, it might be this: "If you drive, take no more than one or at the most two drinks in an evening."

'High School Driver Education is an Important Safety Benefit'

Over the years, many studies have investigated high school driver education programs. Often these studies have been poorly controlled or have not included pertinent variables (McGuire, 1969; Goldstein, 1969). For example, teenage girls drive much less than teenage boys. Therefore, girls tend to have fewer accidents because of their reduced exposure to accidents. In some studies, it has also been found that girls are more likely to take driver education courses. Thus if no separation is made between girls and boys, the results will indicate a reduction in accidents in those taking the courses.

Whenever studies take account of sex differences and driving mileage, a higher proportion tend to indicate little if any benefit from driver education. For example, Table 3 shows results of a California study (Coppin, Ferduin, and Peck, 1965) involving a sample of 10,000 teenage drivers, 6,000 of whom were offered behind-the-wheel-driving instruction in addition to classroom instruction. It may be seen that there was very little difference in the subsequent number of accidents per year of those who took and passed the driver training course and those who did not take it regardless of whether they were males or females. Indeed, because the males who did not take the course drove more than the males who did, comparison on a mileage rate basis would indicate that males who did not take the course had a slightly lower accident rate than those who did. In this study, about the same proportion (21½ percent) of boys and girls elected to take the course. A 1966 study by Conger, *et al.*, showed substantial benefits from driver education but the sample size was small—three matched groups of 40 drivers each. The matching procedure, however, was well done and the quality of this study is probably better than others in this field.

TABLE 3. *High School Driver Education in California, 1965 Study*

Driver Education	Average Number of Accidents Per Year		Average Travel Per Year	
	Males	Females	Males	Females
Took and Passed Course	.158	.076	9,500	4,600
Did Not Take Course	.154	.074	10,800	4,400
Could Not Take Course*	.186	.080	10,600	5,000

* Course was not available in that school or for that student.

Source: Ref. 17

Needed in the driver education field is more research on what should be included in such courses and the best way of enabling people to learn to drive. Perhaps students should be given the opportunity to learn to drive at age 12 with a very minimum of instruction but with many hours of individual practice on specially controlled street and highway networks. Driving is basically a skill and most skills are best learned by practice at a relatively early age. These youngsters would not necessarily be permitted to operate vehicles generally until they were older. Of course any procedures for driver education which evolve from research should be subjected to carefully controlled testing and evaluation prior to full scale implementation. Existing driver education practices also require much better evaluation studies than has heretofore been done. Desirably, students should not be given a choice of taking the course under evaluation but should be assigned to it by chance.

'Enforcement is a Safety Benefit'

Like driver education, research findings on enforcement and safety are mixed. A study by Michaels (1960), for example, reanalyzing a study by Shumate (1958), indicated no significant effect of increased enforcement on accidents or speeds. Some effect on speed variance was noted, but it is doubtful whether it was great enough to produce a change in accidents. Studies have shown that the visible presence of a police patrol car will reduce speeds within the vicinity of the police car (Baker, 1954), but when the patrol vehicle passes from sight, higher speeds are resumed. Other less controlled studies have shown some benefits from enforcement activity. In some cases, changes in other variables such as traffic volume were not investigated. In other cases assignment of troopers on the basis of high accident rates could have seriously biased the studies (Norris *et al.,* 1966).

In summary, it would seem that there is considerable doubt whether additional enforcement really provides added safety benefits. Furthermore, even if better controlled studies indicate some benefit, it is doubtful whether the very high enforcement level required would justify itself in terms of an analysis of benefits and costs. Police patrols do provide badly needed services by summoning aid for motorists who are out of gas, have mechanical trouble, require directional information, or for other purposes.

Other Widely Held Beliefs

Motor vehicle inspection is often thought to be a safety benefit, but there is very little evidence to support this contention (Norris *et al.,* 1966; Garrett and Tharp, 1969). Many states now have various types of motor vehicle inspection, and better quality evaluation studies are needed, particularly of alternative types of inspection procedures.

Similarly, there is little or no evidence to support the value of driver licensing. Indeed, debunking of the myth about the "nut behind the wheel" indicates that driver licensing procedures cannot possibly have more than a trivial effect on safety because of the nearly random occurrence of accidents across the driving population. It is possible to reduce accidents by restricting an entire *group* of drivers, such as those beyond age 65. But this would essentially penalize the entire group for what happens to some of the drivers on the basis of degradation of their faculties and chance rather than on the basis of intent to violate any law. Such procedures have never worked in the United States and run counter to notions of democratic procedure. There is evidence that older drivers restrict themselves to driving less, particularly at night, since they are affected by glare to a greater extent than younger drivers (Solomon, 1964).

The importance of driving is so great in our society that a high proportion of individuals, legally prohibited from driving on a temporary basis, do so anyway. Similarly, some teenagers, aliens, and others will drive although not licensed. These actions raise the question of whether the right to drive is so central in our society that its restriction should be classed as a penalty equivalent to a jail sentence. Clearly such restrictions are not appropriate for mistakes occurring in driving since almost everyone makes mistakes some of the time.

Similarly, registration of vehicles has very little potential for safety benefit although it may assist in recovering stolen vehicles and is certainly useful for revenue producing purposes. A simple, cheap, and more effective procedure for identifying stolen vehicles might be to press the serial number on all new vehicles in a number of places on the body of the vehicle, thus making obliteration relatively expensive. Truck registration for revenue purposes could continue, and passenger car revenue losses could be replaced by an increase of two or three cents per gallon on fuel taxes.

Since little or no positive safety value has been indicated in enforcement, vehicle inspection, or driver licensing procedures, there is little evidence that court or motor vehicle administrative procedures, such as interviews with drivers, are beneficial in terms of reduced accidents (Coppin, *et al.,* 1965). Motor vehicle department letters to drivers may have a favorable short term effect and are cost-effective (McBride and Peck, 1969).

Pure propaganda activities are clearly no more effective in safety than in most other areas of human activity. For example, several years ago a great deal of propaganda was distributed relative to Safe Driving (SD) Day. On this day drivers were to exert all effort to drive as "safely" as possible. Safe driving day arrived and the number of people killed on the highways was about the same as would have been expected on any other day.

Another myth is that installation of stop-and-go signals will invariably reduce accidents. Studies have shown that this is not so (Solomon, 1959). Indeed, at low volume intersections and those of simple geometric design, the number of accidents increased and the number of injuries either showed no change or increased. Rear-end collisions increased 200 percent after installation of stop-and-go signals; the signals required stops by a much higher proportion of all traffic using the intersection. Studies (Solomon, 1959; Foody and Taylor, 1968) do show that installing flashing yellow beacons has a substantial effect in reducing accidents and injuries, and more use of these is desirable.

USEFUL APPROACHES TO SAFETY

In the past, certain measures have demonstrated substantial safety benefits. Included are freeways and control of access, highway design improvements, better vehicle design, shoulder harnesses and lap belts in combination, and certain traffic engineering measures. These will be described briefly as an indication of what a suitable safety program should include.

Freeways Most Important Single Factor

A Bureau of Public Roads study (Cirillo, 1969) makes it possible to estimate that when the 42,500 mile Interstate Highway System is completed in 1975, approximately 8,000 lives will be saved that year as contrasted with the traffic being handled on existing highways. The study also shows that accident, injury, and fatality rates on interstate highways are between 30 and 76 percent of the comparable rates for existing highways. The table below summarizes the comparison.

		Highway		
Rate	Area	Interstate	Existing	Ratio: Interstate / Existing
Accident	Urban	194	637	.30
	Rural	94	213	.44
Injury	Urban	157	259	.61
	Rural	57	137	.42
Fatality	Urban	2.6	3.4	.76
	Rural	3.3	7.6	.43

About three-fourths of all reported *accidents* occur in urban areas. As the above tabulation shows, freeways are very effective in reducing *accidents* in urban areas. Therefore, if the objective is to reduce the total number of accidents with associated accident costs, it is important to build urban freeways. About three-fourths of the *fatalities* take place on rural highways. Freeways reduce the *fatality* rate in rural areas much more than in urban areas. Therefore, if the objective is to reduce fatalities, more rural freeways are needed. In summary, additional mileage of both rural and urban freeways is needed to enhance safety, reduce congestion, and generally improve transportation.

Highway Design Details

Over the years, many studies of highway design details indicate that close attention to these details can yield safety benefits. However, it must be emphasized again that they are not substitutes for full control of access. The best designed highway that permits frequent access from roadside businesses and numerous intersections will have a high accident rate regardless of the adequacy of highway design details. Studies by Raff (1953), Cirillo (1969), and Schoppert (1963) define the effect of highway design details on accidents.

On conventional rural highways, for example, very sharp curves or very sharp curves and steep grades in combination have an especially adverse effect on accidents. On interstate freeways, which already have very high design standards, among the features that most consistently exhibited a reducing effect on accidents were adequate bridge clearances (Cirillo, 1966), paved rather than unpaved right shoulders, existence of delineators, and increased stopping sight distance (Cirillo, Deitz, and Beatty, 1969).

Improved Vehicles

Over the decades many improvements in vehicles have been made that could influence safety. These include automatic transmissions, which make the driving task easier; better visibility through windshields, side windows and rear windows; steel tops; better structural design of the vehicle, and others. However, except for the importance of adequate horsepower noted earlier, few studies have examined the specific benefits of these improvements in terms of accident reduction.

It has been shown that both lap belts and improved door locks can reduce ejection from the vehicle and consequently reduce the severity of injury. The benefits from improved windshield design for minimizing the severity of forward impact accidents have also been demonstrated (Norris, *et al.,* 1966).

Shoulder Harnesses and Lap Belts

The effectiveness of lap belts in reducing vehicle ejection is quite clear. Unfortunately, only a fraction of all drivers wear lap belts at any one time. Moreover, for drivers involved in accidents who are not ejected, the evidence indicates that lap belts tend to convert lacerative type injuries into concussive injuries. Studies in Sweden have indicated that a combination of lap belts and shoulder harnesses is effective in injury reduction, but the problem is how to get a large proportion of drivers to use these devices.

Traffic Engineering Measures

One-way streets generally tend to decrease accidents. Conversion from angle to parallel parking, or complete removal of parking, generally reduces accidents.

Studies have shown that a reasonably high coefficient of friction between pavement surface and tire is essential to minimize skidding accidents in wet weather. Pavement edge markings have been shown to reduce accidents near rural highway intersections. Accidents are generally greater on roads where the bridge width is narrower than the pavement width, but it is doubtful whether widening these bridges would be cost-effective.

Impact Control Devices

Studies have shown that break-away sign supports and break-away lighting poles are quite effective in reducing the severity of accidents. Guardrails help reduce accident severity at piers, abutments and other structures. Median barriers appear to reduce fatal accidents but increase total accidents. The use of special types of impact attenuation devices in advance of gores, piers and abutments appears to be promising.

AN UNBALANCED HIGHWAY SAFETY PROGRAM IS NEEDED

The foregoing summary of current myths and useful past approaches suggests to the writer certain conclusions:

1. Activities directed at reforming, educating, propagandizing, or in other ways harassing the driver have, in general, not been effective, although in a few cases the evidence is not conclusive.

2. These non-productive activities have set back constructive safety efforts several decades because they have diverted attention from activities that are effective.

3. Engineering measures applied to the highway and vehicle have been shown to be effective in many although not in all instances where they have been evaluated.

4. More complete evaluation of devices, techniques, and systems proposed is badly needed.

5. It is undesirable to continue the balanced safety program that was suggested as early as the 1924 Hoover Conference On Highway Safety.

6. Needed is an unbalanced safety program, i.e., a program that gives primary emphasis to engineering activities and particularly to engineering research and development.

An unbalanced highway safety program is suggested below. Its cost is considerable, but it should be viewed in the context of the cost of highway accidents that will probably exceed 400 billion dollars over the next 20 years. The even greater human cost of pain, suffering, and family dislocation resulting from highway accidents must also be considered in evaluating the proposed program.

Build More Urban and Rural Freeways

As indicated earlier, urban and rural freeways are the most effective proven method of reducing accidents, accident costs, injuries, and fatalities. When the Interstate Highway System is completed, more than 20 percent of all travel will be accommodated on the system. To increase this percentage to 60 percent of the travel would probably mean more than quadrupling the mileage of freeways since the effect of diminishing returns sets in. This could require additional expenditures in excess of 200 billion dollars over a period of approximately 20 years.

Such expenditures would probably be cost-effective because the benefits of freeways include savings in travel time and operating costs as well as savings in accident costs, injuries and deaths. Again, because of the effect of diminishing returns, handling an additional 40 percent of all traffic on freeways would probably save less than an additional 16,000 lives each year; but savings in lives should be substantial, and perhaps an additional 12,000 lives would be saved each year.

Expand Research and Development

An expanded research and development program should include research into fundamental aspects of driving to provide a good understanding of the types of information and assistance drivers need in order to operate their vehicles efficiently on the nation's highways. Research is also needed on the interaction among drivers in traffic, leading to development of vehicle-highway-control systems that better fit the capabilities and limitations of the driver.

Development of more promising systems should proceed at a rapid rate. Testing and evaluation of all new developments should be done very carefully on a pilot basis so that the driving population is not subjected to untested techniques. Included in the evaluation procedure should be laboratory and test track studies and, finally, limited pilot evaluations on selected highways. Operational programs that are seriously in question should also be subjected to careful evaluation. Included are driver education, enforcement and other current programs that have not been suitably evaluated. New programs proposed should be subjected to similar evaluation procedures.

Research and Development Must be Done on a Systems Basis

Highway transportation operates as a system comprised of vehicles, highways, control systems and devices, and the driver. Nearly all research and development must consider two, three and, in many cases, all four of these interacting elements. Highway geometric design standards, for example, have been based on research that studied the reaction of the driver and his vehicle to various types of geometric design. Power requirements for vehicles depends on vehicle weight and highway gradient. Hundreds of examples of the interaction of this system could be given.

Another example of interaction is culvert design that depends primarily upon rainfall and runoff characteristics, but the amount of water that may be tolerated on the pavement is determined by tire and pavement surface-interaction and driver reaction. Moreover, culvert headwalls and cross-section need to be designed to accommodate vehicles leaving the pavement (Hutchinson and Kennedy, 1966). With respect to safety, the interactions, if anything, are more important than with respect to other measures of performance of the highway transportation system.

However, although it is essential that research and development recognize the inter-relatedness of the elements of highway transportation, it is also true that implementation of research and development results can and often are put into use separately for highway, vehicle, and control systems. For example, after completion of research and development on a systems basis, changes in highway geometric design standards are made by the Bureau of Public Roads and the American Association of State Highway Officials and implemented by highway engineers across the nation. Similarly, after research has been completed involving trucks, drivers, and highways, requirements for additional horsepower for trucks are set by the National Highway Safety Bureau and implemented by the motor-vehicle manufacturers.

It is essential to understand that research and development must be carried out on a systems basis while implementation can and often should be done separately. To carry out research and development involving only one system element such as the "driver" or the "highway" is impossible except in certain specialized areas. Research involving the driver must specify the characteristics of the vehicle and the highway environment. The most fundamental type of research in a laboratory simulator employing a simplified cathode-ray type of display may require only two converging lines to simulate a roadway—but the roadway must be there to carry out the research. Moreover, it must be recognized that coordination is required in implementing many new devices and procedures. For example, the increased mileage of interstate freeways has permitted hours of continuous driving at speeds in excess of 70 miles per hour and has forced the use of tires suitable for such operation.

In summary, sustained cost-effective progress in highway safety requires an adequate research and development program on a systems basis to include (1) Research to develop new knowledge, (2) Development to translate this new knowledge about highway transportation and highway safety into new systems, devices, and techniques to aid the driver, and (3) Careful test and evaluation of both proposed innovations and ongoing programs. Described below are some aspects of a research and development program which the writer believes will have possibilities for useful payoff in terms of highway safety. These programs will frequently produce non-safety benefits including improved traffic flow, reduced travel time, etc. Therefore, program formulation must consider other aspects of transportation in addition to safety.

Research to Provide New Knowledge

Development of new devices, techniques, and systems for aiding the driver and providing improved traffic flow and safety must proceed from a base of understanding of drivers' needs, desires, limitations, and capabilities. Otherwise, drivers will neither want nor be able to use these new products. Although considerable information is available to meet this requirement, more fundamental research is needed to determine how drivers operate their vehicles in a wide variety of traffic situations. Included are such questions as how drivers maintain steering control and lateral position; how they judge relative velocity with the vehicle ahead and maintain the gap required; how they make judgments in merging, crossing, and other maneuvers; how they maintain position under adverse visibility conditions such as darkness and rain; and how they make judgments of the speed and closing rate of overtaken vehicles on two-lane highways.

Also needed is additional research on traffic flow—the interaction of large numbers of vehicles. Operation at very high speeds, in the order of 80 to 120 mph, requires an extension of previous research to encompass these higher speeds. The problem of tire-surface interaction, particularly on wet pavements, is critical at very high speeds. This interacting subsystem in turn is related to the stability of the vehicle and the flow of traffic.

Development of New Systems Needed

Based on research findings, new motorist-aiding systems should be developed which will give drivers information that they need and can use about many common traffic situations. Such information includes relative speed or closing rate or time to overtake a vehicle ahead; time to meeting an opposing vehicle on two-lane rural highways; the incidence of stopped or slowed traffic ahead; routing information, particularly on freeways and city street networks; aid in merging at on-ramps; advance information that vehicles ahead on city streets will stop to pick up passengers or turn left or right, and many other situations in traffic. Ultimately these *functions* should be combined into an overall integrated motorist aiding system which will help drivers in a wide variety of highway and traffic situations.

Another broad area of research and development involves providing improved impact attenuation systems beside the roadway in concert with redesign of the structural frame of the vehicle front, back, and side. Cost effectiveness trade-offs are very important in this development effort, and such trade-offs should be included from the outset. For example, if structural redesign of the vehicle is completely successful, considerable savings in guard rail, break-away signs, and other impact attenuation devices may be feasible. On the other hand, if the effort is only partially successful, these roadside structures may continue to be useful and cost-effective, although they may need to be redesigned to account for new design of the structural frame of the vehicle.

Great progress in structural redesign of the vehicle and highway impact attenuation devices will not solve the problem of injury reduction if the vehicle occupant is permitted to move forward and sideways in an unrestrained fashion. Lap belts and shoulder harnesses in combination have been shown to be effective and are probably cost-effective. However, as noted earlier, only a fraction of all car occupants use these restraint devices. Air bag restraint systems appear to have considerable promise if triggering and other associated problems can be solved. Therefore, considerable development work is warranted on air bags and/or other occupant restraint systems in concert with the structural redesign of the vehicle and highway impact attenuation systems.

Trends over the past 20 years indicate an increase in average rural highway operating speeds of about one-half mile per hour per year (Speed Trends, 1969). However, within the past five years, annual increases have been slightly greater. Thus rural freeways which now operate at average speeds of 65 miles per hour might attain average speeds of 75 miles per hour 15 to 20 years hence. It may be instructive to attempt to predict changes in fatality rates for these freeways if no improvements are made in the freeway, vehicle, and control system. As shown in Figure 6, at 65 miles per hour, 3.5 persons are killed for every 100 vehicles involved in accidents. At 75 miles per hour, 7.5 persons are estimated to be killed for every 100 accident-involved vehicles, an increase of about 100 percent. Assuming (1) the *accident* rate does not increase at higher speeds and (2) the single points chosen in Figure 6 represent the speed distribution, the future *fatality* rate should also increase about 100 percent.

In a similar fashion, from Figure 6, future fatality rates on conventional rural highways are estimated to increase about 100 percent. In this case, the same assumptions are made except that speeds are presumed to increase from present average speeds of 60 miles per hour to speeds of 70 miles per hour, 15 to 20 years hence.

Figure 7 includes the same data as Figure 6 but plotted on a linear scale to better show the relationships. The beginning of the steep upward trend in the curves occurs at speeds of 70 miles per hour on freeways and 60 miles per hour on conventional highways—speeds equal to present average speeds for conventional highways and only 5 miles per hour higher than average speeds on freeways. Therefore, unless engineering improvements are made, future upward speed trends will almost certainly result in substantially increased fatalities.

The relatively slow year by year increases in highway operating speeds suggest two things: first, the nationwide increase in fatality rates due to generally higher operating speeds may not be immediately evident and may delude us into taking no action now; and second, adequate time is available to do the necessary research if efforts are started now rather than waiting for the higher speeds and increased fatalities which will result.

The results of higher speed operation are becoming apparent on a few rural freeways where average operating speeds approach 70 miles

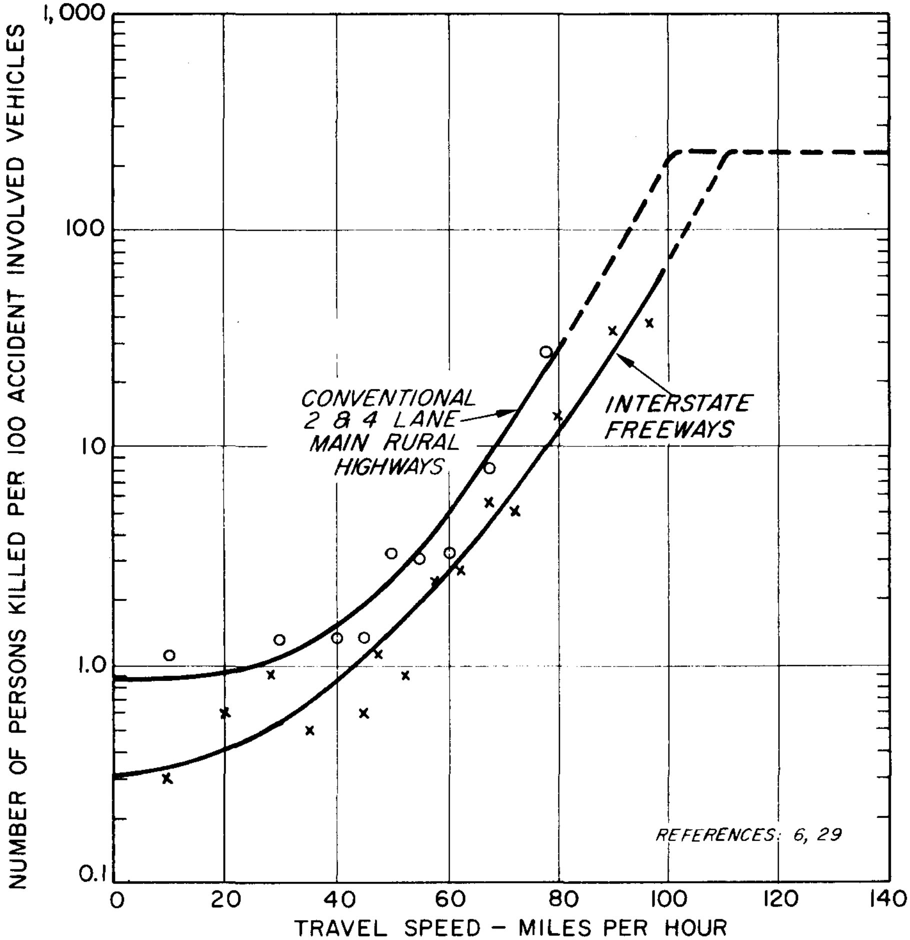


FIGURE 6. *Persons Killed Per 100 Accident-Involved Vehicles at Various Travel Speeds on Conventional and Interstate Highways*

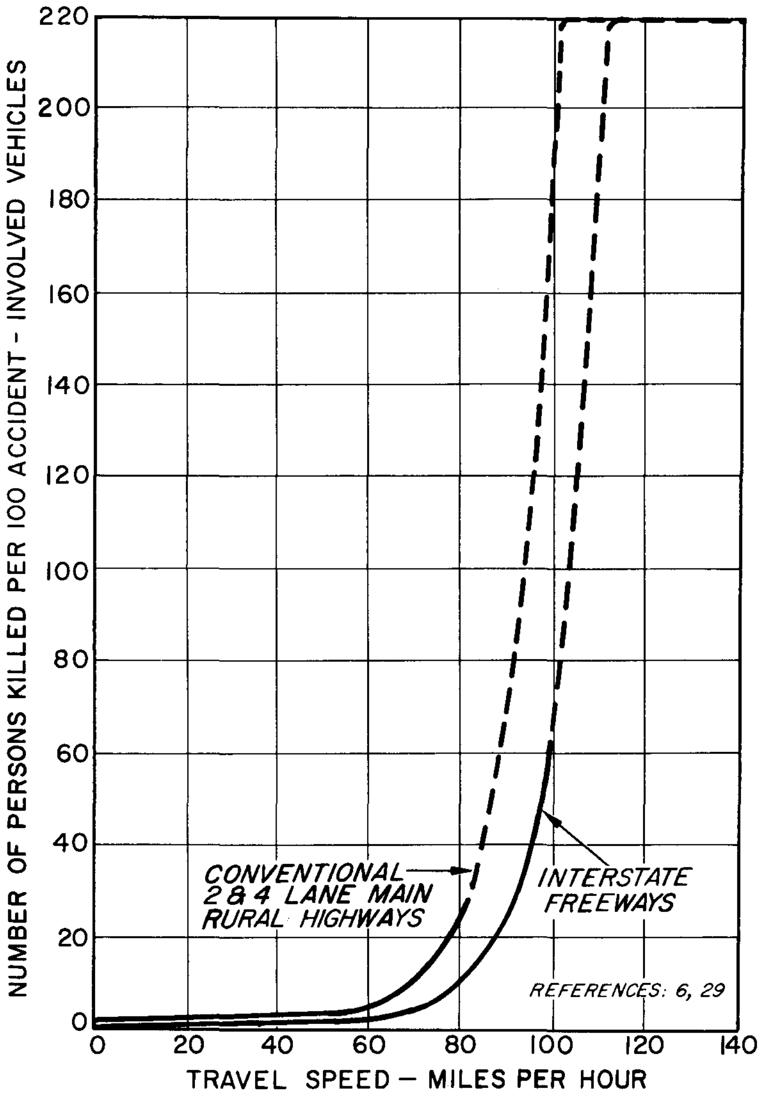


FIGURE 7. *Persons Killed Per 100 Accident-Involved Vehicles at Various Speeds on Conventional and Interstate Highways*

per hour. The fatality rates in these instances are about 50 percent higher than on typical rural freeways where average operating speeds are 5 to 10 miles per hour lower.

The foregoing discussion demonstrates that research should be directed *now* at higher speed operation on both conventional highways and freeways. Operating speeds as high as 80 to 120 miles per hour should be considered as part of all the preceding research and development efforts. Certain problems will need additional research effort for these higher speeds including tire-surface interaction on wet, dry and icy pavements as related to super-elevated or crowned highways and vehicle handling characteristics. Anti-skidding systems will need to be developed. Problems of night visibility and glare will require special attention. Many other problems will also need to be identified and investigated.

Carefully Planned Testing and Evaluation are Essential

As indicated earlier, all new systems developed should be subjected to very careful test and evaluation procedures including cost-benefit or cost-effectiveness analyses. Indeed, the cost-effectiveness analyses should be repeated during the development effort. Greater precision and reliability of cost-effectiveness analyses should be possible in the latter phases of the R&D effort.

The test and evaluation phase requires very careful planning and tight control of experimental procedures. Some of the work will be done in laboratory or test track environments where careful control can be readily and cheaply obtained. Eventually, however, most if not all systems and techniques must be subjected to field testing and evaluation which also requires careful planning and tight control of the experimental work—but here much more difficult to achieve. Very careful evaluation with adequate controls and adequate analysis of the results is essential. See Campbell (Campbell, 1970) for a very good discussion of the importance of such procedures.

Included in the test and evaluation procedures should be existing programs for which additional evaluation is desirable. These include high school driver education, various types of driver training, enforcement techniques, etc. There is doubt whether these non-engineering techniques will prove to be cost-effective. Many may not even be per hour. The fatality rates in these instances are about 50 percent higher than on typical rural freeways where average operating speeds are 5 to 10 miles per hour lower.

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Included in the test and evaluation procedures should be existing programs for which additional evaluation is desirable. These include high school driver education, various types of driver training, enforcement techniques, etc. There is doubt whether these non-engineering techniques will prove to be cost-effective. Many may not even be effective. However, because they are ongoing programs, very thorough testing and evaluation will be required before the programs can be abandoned or substantially modified. This is an important reason for *not* implementing unproven programs on a large scale. Once such programs are instituted, they become very difficult to abandon because of vested interests that are built up around them.

Anti-alcohol programs may be particularly fruitful areas for payoff if carefully evaluated prior to nationwide implementation. Substantial benefits have come from such programs in England and in other European countries. Pilot programs in perhaps two or three states might prove the utility of such programs in the United States. Two allowable blood alcohol levels could be tested employing breath analyzers for aid in enforcement. Given the experience of prohibition, it is by no means certain that such programs would be effective in the United States but they appear worth testing on a pilot basis.

Improve Details of Vehicle and Highway Design

Knowledge is available of certain aspects of highway and vehicle design which are cost-effective and are not now in wide use. Such improvements should be implemented although they will produce only a modest change in highway safety. Three examples follow: right shoulders should be paved for those few freeways not having paved right shoulders; access to new two-lane highways from abutting businesses should be restricted; very low powered vehicles relative to their weight should not be manufactured.

SUMMARY AND CONCLUSION

1. An unbalanced highway safety program is needed giving priority to (a) research and development, (b) construction of more urban and rural freeways, (c) attention to engineering aspects of the vehicle, highway, and control system, (d) evaluation of such unproven activities as driver education, enforcement, driver licensing, etc.

2. The vastly expanded research and development program required should include fundamental research relative to the driving process and traffic flow; development of new traffic systems; structural redesign of vehicles, occupant restraint systems, and roadside structures in concert; special attention to future high speed operation; and

very thorough test and evaluation procedures for proposed and existing techniques, systems, and devices.

3. Slogans and myths have pervaded the highway safety field for decades. These myths have hindered good safety programs from being implemented and have aided in retaining unproven and ineffective programs. In truth, the bad safety program drives out the good.

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DISCUSSION

B. J. Campbell

Dr. Campbell brings the skills of an experimental psychologist to the field of highway safety. He received his B.A. and M.A. from Texas Christian University, and his Ph.D. from the University of North Carolina. He first became involved in the problems of traffic safety when he took a position with the University of North Carolina Institute of Government and completed a study of the point system in driver improvement.

From 1958 to 1959 he was Assistant Director of the Institute of Government. He left to become Assistant Director, Automotive Crash Injury Research, Cornell University. In 1962 he became Head of the Accident Research Branch of the Cornell Aeronautical Laboratory. He then accepted an invitation to return to his alma mater to head the newly established University of North Carolina Highway Safety Research Center.

In 1960 Dr. Campbell's research was recognized when he received the National Safety Council's Metropolitan Life Award for Research in Accident Prevention. In 1971 he received a Certificate of Commendation in the same competition. His major interest lies in the evaluation of the effectiveness of safety programs.

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I have listened with great interest to my friend Dave Solomon's paper. The things he has said need to be said, and his words deserve your careful consideration. Dave's paper is a good and important one.

There can be no quarrel with the speaker's call for objective, scientific evaluation of highway safety programs—nor with the concept that only those highway safety programs that prove themselves effective deserve support. I further believe that the burden of proof of the worth of the programs should lie on the advocates of said programs.

I would like to offer two cautions that should be considered in the process of program evaluation:

1) researchers should expect that many programs will turn out to have low benefit/cost ratios.
2) researchers should remember the special importance of a Type II error in program evaluation research.

Benefit/Cost Ratios

As a rule of thumb some people, including myself, talk about a "break even" ratio in terms of cost-benefits. We refer to highway safety programs that are sufficiently effective to bring about a one dollar reduction in accident costs for every program dollar spent. We also speak hopefully of programs in which the reduction in accident costs may even exceed program costs. Programs that are "break even" or better make good sense on any basis, whether it be economic, compassionate or whatever (providing, of course, that the program does not seriously impair the mobility for which the highway system is designed).

However, in various instances, it may be unrealistic to hope for programs with a "break even" cost/benefits ratio. I believe that as a society we are willing to accept much less favorable ratios. We are probably willing to accept a return of, say, only 50 cents of accident cost reduction for every program dollar spent. In the context of compassion and morality as well as economics, this may be a return that society is willing to accept. Of course, among *several* programs we should insist on support for the ones that are the most favorable—or the ones having the least unfavorable benefit/cost relationship.

As an example, I would like to cite seat belts. I suppose most of us would regard seat belts as a successful and highly acceptable program. The country has accepted legislation by which seat belts are installed in all cars. The benefits of seat belts in reducing injury are, I assume, not contested. There was even one study that suggested the seat belt to be a marvelous success on a costs/benefits basis. However, that study presumably weighed the cost of *one* seat belt against the obtainable reduction in injury if that one seat belt were used.

I would like to submit that seat belts are actually accompanied by a rather unfavorable benefit/cost ratio. Out of every ten thousand belts placed in the car, only about eight hundred will be in an accident in any given year. Of the eight hundred belts in the car, only about seventy-two will be in use. (These figures are based on North Carolina statistics.) Of the belts in use, some will not make a difference—sometimes the person wouldn't have been injured even if he were not using the belt. Other times he will be seriously injured or killed *despite* using the belt. On the plus side, in relevant cases, the injury reduction is very substantial. Furthermore, the cost of the belt can be amortized over a five-to-eight-year period. At best the seat belt barely reaches the "break even" level.

This level of cost versus benefit is readily accepted by the public, highly advocated, and is considered to be a "howling success." The point of this example is that if this kind of benefits/cost ratio is acceptable in this area, then presumably programs that are far below the "break even" point are also acceptable in other subject matter areas.

Now let us consider the second point—the importance of the Type II error. If we attempt to calculate the expected benefits and evaluate a highway safety program, we might follow a procedure like this: We take the total cost of the program and divide it by 1,000 (which is approximately the average cost of an accident). This yields the number of accidents that must be prevented by the program. This number, divided by the total number of accidents the program could be expected to affect, is the percent accident reduction that must be achieved by the program in order to break even.

Suppose, therefore, that a given safety program must bring about a reduction in a certain accident subclass of 20 percent in order to break even. However, if we set our goals a bit lower and say that we are willing to accept a one to five benefits/cost ratio, then the percentage reduction in accidents required to justify the program is only four percent.

Now I ask you to consider the kind of experimental design, the sample size, and the statistical analysis needed to achieve an accurate detection of a four percent change in a phenomenon as complex as accidents. It would take quite a sensitive measure wouldn't it? Asking that question brings us the question of the Type I and Type II errors.

You will recall that a Type I error is the risk of saying that a change has occurred when in fact no change has occurred (i.e., rejecting the null hypothesis when it is true). The alpha level of our statistical tests defines this level of risk. Traditionally, we set this risk of a wrong decision at five in one hundred or one in one hundred.

You will recall also that the Type II error is the risk of stating that *no* change has occurred when in fact a change *has* occurred (i.e., the risk of "accepting" the null hypothesis when it is false). In the context of theoretical research, we worry considerably about the Type I error and wish to guard against it by setting rather rigid alpha values. The reasons for this are clear. In the context of a theory developing research, we want to be sure that we do not say that something is so when it is not so. We do not want to add findings to the scientific literature when it is in error. By setting a rigorous barrier against the Type I error, we of course increase considerably the probability of a Type II error. Again, in the context of theoretical research, this is no great matter because if we fail to document a particular phenomenon, some other scientist will discover it, or *we* will discover it at a later time. Ordinarily, we do not mind saying that we have found no effect when in fact there was one.

However, when it comes to evaluation of on-going highway safety programs, the Type II error takes on a new importance. It is of *considerable* importance to avoid saying that a highway safety program has no effect when in fact it *has* an effect. Because to say so may create pressures to reduce support for the program. If the program is indeed modestly successful in saving lives, harm would be done by denying support for such a program. When this point is combined with the fact that sometimes the expected degree of reduction is very small (recall the first point above), then the risk of a Type II error is very high indeed.

It is equally important, of course, to avoid saying that the program works when it has *no* benefit. The point is that there must be a balanced consideration of Type I and Type II errors.

In summary, I want to stress the considerable importance in proceeding with care in the interpretation of findings in which an attempt has been made to detect a change associated with a given program, and no such change was detected. The appropriate interpretation and its implications for action are not nearly as clear cut as in the context of more academic, theory-building research.

Section III

The Highway Contribution to Accident Generation

Kenneth J. Tharp

Discussant

Wesley Grigg Mullen

KENNETH J. THARP

It was a homecoming for Dr. Tharp when he arrived to participate in this symposium. He completed his M.S.C.E. at North Carolina State University before going to Purdue University for a Ph.D. with a major in transportation engineering. He has taught at Duke University, Purdue University, and State University of New York in Buffalo.

Dr. Tharp combines academic and research experience with considerable on-the-job experience acquired in Iowa back in the early 1950's. He has also operated his own consulting engineering firm while pursuing his graduate studies.

He is now Principal Systems Engineer, Transportation Research Department, Cornell Aeronautical Laboratory, a position he has held for a number of years. His publications have stressed the relationship between highway design and accidents. He has also contributed to the methodology of studying and reducing accidents.

THE HIGHWAY CONTRIBUTION TO ACCIDENT GENERATION

By Kenneth J. Tharp

One major difficulty encountered in discussing many subjects is a failure to speak a common language. Highway safety is no exception and many misunderstandings occur because different people apply different meanings to many of the words and terms used. In order to minimize the possibility of misunderstandings due to semantics, a few of the more pertinent terms will be defined as a guide to the subject material.

"Accident," a word that arouses mixed emotions in various people, is defined as an unintentional and unexpected occurrence involving property damage, injury, suffering, or death. "Unintentional" indicates that the occurrence and especially the accompanying loss would have been avoided if the people involved had had the opportunity and ability to do so. In a motor vehicle accident, the "occurence" is the series of events that occur immediately prior to, during and after the actual collision or crash and which have a relationship to the collision.

"Highway" has a dual meaning: first, "highway" as used in the term "highway safety" infers a system composed of driver, vehicle, highway facilities and environment—a more descriptive term would be "highway transportation system"; second, "highway" as used in "highway facilities" refers to the physical plant and includes the surface over which the vehicle moves, the signs and signals for regulating traffic movements, and all other constructed facilities. Thus, "highway" in this sense is only one component of the highway transportation system. In the title of this presentation, highway is used in the restricted sense.

Highway safety is concerned with both the prevention of accidents and the mitigation of the loss resulting from accidents upon the highway system. The objective of this paper is to briefly discuss the role which the highway component (or the physical plant) of the system plays in generating accidents and in controlling their severity. In order to meet this objective it is necessary to have an understanding of the entire highway transportation system, its operation, its function, and what constitutes an accident.

System Components

The highway transportation system may be considered as being composed of four components: 1) driver; 2) vehicle; 3) highway—or static environment; and 4) ambience—or dynamic environment.

The *driver* is the unique component of the system and may be described in several ways: he is the active responsive component of the system; he possesses intelligence and, therefore, has the ability, and is expected, to observe, reason, make decisions, and otherwise respond to stimuli; he is the component which controls the movement of individual vehicles throughout the entire system; the driver is the only component that has the capability and opportunity to adjust or compensate for any variations or deficiencies occurring within the system.

In order to perform the driving task, the vehicle operator must receive data related to his vehicle, its motion, the highway, and the immediate environment. He must understand and interpret the meaning of these data. He must make decisions with due regard to his abilities and experience, the capabilities of his vehicle, highway rules and regulations, the physical laws of motion, and many other factors. When decisions are made, the driver must then initiate the muscular activity that activates these decisions.

"Accident" has previously been defined as an unintentional occurrence; therefore, the driver will avoid all such events if he has knowledge of impending danger and if he has the opportunity to modify or correct his vehicle's motion prior to the actual collision.

The *vehicle* is a machine, designed with certain mechanical features that, under the control of the driver, permit self-movement, aid the driver in his control task, and provide certain conveniences and luxuries for the driver and passengers. There are also vehicle features that hinder the driver in the driving task—visibility limitations and restrictions, varying vehicle handling qualities, etc. When the highway transportation system is functioning properly, the driver knows, and does not exceed, the capabilities of his machine and the machine's mechanical responses are predictable and known.

The *highway,* or physical plant, includes the surface over which the vehicle moves, signs and signals for controlling traffic movements, signs and markings for informational purposes, and other constructed facilities, designed and controlled by the highway or traffic engineer. With the exception of certain preprogrammed responses such as traffic signals, the highway is generally passive and, in any case, cannot be modified or changed by the individual driver during the driving task—that is, the driver has to accept the highway as he finds it and must adjust to, or compensate for, changes in it. The driver must be made aware, or presented with adequate notice, of required patterns of traffic flow, changes in the facility and other design features so that he may control his vehicle in accordance with the intended usage of the physical plant.

The *ambience,* or the dynamic environment, is the time variable environmental conditions under which the system operates and includes the weather, other traffic, natural visibility limitations, temporary road conditions, etc. Adverse environmental conditions may be modified by proper maintenance and design—e.g., snow removal, sanding of icy roads, installation of roadway lights, and construction of enclosed roadways, etc. However, the individual driver must accept the ambient conditions as they are on a particular highway at a particular time—that is, the individual driver cannot change or modify his ambience but has to adjust or compensate for it. An individual driver does, however, change or contribute to the ambience for other road users by the presence of his vehicle, the motion of his vehicle, signals, etc.

Collectively these components constitute the highway transportation system of which the function is the movement of goods and people. The performance of the system is commonly evaluated by reference to quantities such as the amount of goods moved, the number of people moved, the cost of movement, the speed of movement, the number of disruptions to the movements, and so forth. The unintentional disruptions to the function of the system, which result in additional property damage, injury or death, are accidents as previously defined. Intentional disruptions (vehicle checks by police, blocked-off construction areas, etc.) and disruptions without additional damage (flat tire, a flooded roadway, etc.) are not accidents but may become a factor in the generation of accidents.

System Operation

The operation of an individual vehicle-driver unit is essentially a closed continuous loop of data supplied, perceived, decisions made, human action taken, and mechanical response. The accomplishment of each step requires an increment of time—driver observation may require an extremely short time period, driver perception and reaction may take a fraction of a second to several seconds, and the necessary adjustment of vehicle speed or direction of motion may require several more seconds. These elapsed time periods may become critical in the avoidance of accidents in the highway transportation system. That is, when information is *not* available to the driver in sufficient time for the adjustments and compensative actions to vehicle speed and direction to become effective, a system failure, or occasionally an accident, may result.

Figure 1 is a graphic illustration of the operation of an individual motor vehicle within the transportation system.

System Failure

By definition, a system failure cannot occur when all of the components of the system are functioning properly—in other words, if all components are functioning as expected and desired, the transportation system is operating as intended and without disruption. However, if one or more components malfunction in any way, there *may* be a system disruption that may result in an accident.[1]

The successful performance of the transportation system is primarily dependent upon the driver because:

a) his functions in the operation of the system are numerous and complex, involving receiving information from the entire system, comprehending this information, making decisions, and activating the decisions.

b) the driver can adjust or compensate for performance failures or deficiencies in the system if he is given adequate information on deficiencies and allowed adequate time for adjustment. If the driver does not adjust or compensate for these deficiencies, he is generally "charged" with a failure.

c) the driver fails or performs deficiently upon occasion and the passive components of the system cannot adjust for his failures.

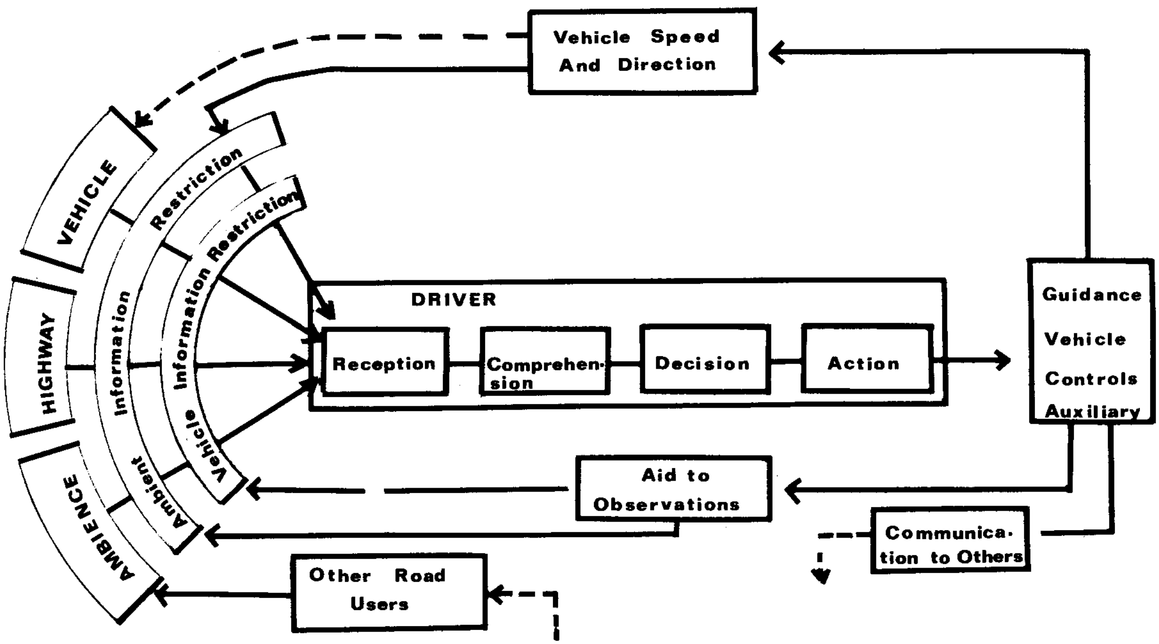

FIGURE 1. *Flow Chart of Driver-Vehicle-Highway-Ambience System Operation*

FIGURE 1. *Cont.*

- VEHICLE, HIGHWAY, AMBIENCE and VEHICLE MOTION are information sources for the driver.
- Information passes through both AMBIENT and VEHICLE INFORMATION RESTRICTIONS.
- AIDS TO OBSERVATIONS are the auxiliary equipment within the vehicle which either improve reception of signals—windshield wipers, headlights, etc.—or provide vehicle and motion information—speedometer, engine operation gauges, etc.
- The DRIVER RECEIVES or becomes aware of the information presented to him from the various sources.
- The DRIVER COMPREHENDS or understands the meaning of the information received.
- The DRIVER DECIDES upon a course of action. This may be either an immediate response decision or a long term driving technique.
- The DRIVER undertakes physical ACTION.
- The driver's physical actions result in adjustment of the VEHICLE CONTROLS: GUIDANCE—control of vehicle speed and direction of movement; AUXILIARY—operation of driver aids or information transmittal devices.
- VEHICLE SPEED and DIRECTION are regulated by the guidance controls subject to certain physical laws (coefficient of friction, $F=Ma$, etc.) and vehicle mechanical limitations. Information concerning vehicle motion is transmitted to the driver through the vehicle information channels—speedometer, etc.
- Vehicle motion modifies the condition of the vehicle: normal usage results in wear and tear on mechanical elements and eventual component failure: overloading, riding of brakes or other improper driving procedures will cause a more rapid deterioration of vehicle elements and will change handling characteristics.
- COMMUNICATION TO OTHERS—turn indicators, horn, etc. whose output becomes part of the *ambient environment* for other road users (the communications from others become part of the ambience for the subject driver).

Therefore, the driver has the key role as the *active component* in the motor vehicle accident problem and the vehicle, highway and ambience are *passive* components. This approach to the problem does *not* exclude malfunctions or failures of any component of the system but does stress driver reliance and dependence upon the system components and upon the information provided to the driver concerning the condition of the components as they *affect* the driving task.

Malfunctions

Component malfunctions or failures are defined as those instances when the component does not *perform* as *designed* or *intended.* The words malfunction and failure will be used interchangeably.

Driver malfunctions occur when he fails in one or more of the multitude of tasks required in the intelligent operation of his vehicle—specifically, he fails to receive available information, or he does not comprehend, or he makes an improper decision, or he fails to physically activate the decision within a reasonable increment of time. Although identification of general driver failure in a particular accident is normally possible, the determination of a specific driver failure is often difficult as adequate information may not be available to specify the failure in detail.

Vehicle malfunctions occur when the vehicle fails either mechanically or structurally so that the normal operation for which the vehicle is designed becomes impossible—i.e., an element or vehicle component cannot function as designed. The failure often occurs suddenly and without warning. It may result from improper use and maintenance of the vehicle. These malfunctions include structural failure of some mechanism within the vehicle, failure in the electrical system, a tire blowout, etc. There is generally physical evidence of the failure after the collision and the major problem during accident investigation is to determine whether the failure occurred prior to the collision and generated the accident, or whether the failure was a result of the collision.

Highway malfunctions occur when a feature of the physical plant does not serve the driver as intended by the highway designer or the traffic engineer. A burnt out light in a traffic signal would be a malfunction, or the structural collapse of a bridge, etc. There is physical evidence of these failures after the collision.

Ambient malfunctions are those rare instances when an "act of God" completely disrupts a segment of the transportation system—landslides, tornados, washed out roads, etc. These malfunctions or evidence of them could be documented by physical evidence after the collision.

Conditions

Conditions are defined as those items for which the driver must compensate, adjust, or give special consideration. Conditions are not component failures but increase the likelihood of a driver malfunction by either decreasing driver efficiency and ability or presenting the driver with additional problems.

Driver conditions are physical, mental, or emotional impairments which reduce the efficiency of the driver and thus increase the probability of his malfunctioning. Extreme driver conditions would be blackout or dozing, either of which indicates that the driver is completely incapable of performing at that time. Less extreme conditions (variable in effect) involve fatigue, intoxication, illness, inexperience, emotional factors, etc.

Vehicle conditions require the driver to make special adjustments or use special care in the operation of the vehicle or in obtaining needed information. Many of these are design features which function as designed but require the driver to make special adjustments in the driving task. Others are owner or operator variations of design features and a large number are maintenance items. Examples are: vehicle information restrictions such as view obstructions by the vehicle corner post which require the driver to lean forward to see certain roadway features; changes in control locations so that the driver has to concentrate upon their location; incompatibility between driver size and vehicle size so that the driver has utilized pillows on the seat and blocks on the pedals in order to activate the controls; difference in handling qualities resulting from low tire pressure or poor adjustment of the vehicle's brakes, etc.

In a few instances the separation of vehicle malfunctions from vehicle conditions becomes difficult. For example, an extreme brake condition which requires pumping of the brake pedal prior to obtaining retarding forces may, in effect, be a malfunction during an emergency situation.

In many instances, familiarity with a particular vehicle will result in mitigating the effects of vehicle conditions because adjustment to these conditions will become part of the driver's normal operation of that vehicle. However, effects of vehicle conditions may appear in moments of driver stress or in those instances when he is occupied with other tasks and thus fails to allow for a known condition.

Highway conditions are the designed features of the physical plant which require special driver adjustment or compensation for the desired traffic movement. Examples are: geometric designs which require unnatural vehicle travel paths; geometric features which require immediate and excessive speed changes; a short amber signal phase which does not provide for a positive time separation of traffic flows at an intersection, etc. Again, the effects of highway conditions are likely to appear in moments of driver stress or when other tasks and conditions require his attention. By definition, imperfections such as chuck holes, ruts, etc., in the road surface or shoulder are conditions and not malfunctions as the road is usable within limitations.

Ambient conditions are the natural, undesigned and transient elements of the environment to which the driver must adjust. Because the environment is always present, the adjustment is a matter of degree and not a "yes-no" solution. In other words, the ambient conditions range from "good" to "bad" and may be evaluated (generally qualitatively) between the two extremes. In most accident investigations, the emphasis is on adverse conditions or those which the investigators believe presented the driver with additional driving problems. These include slick roads, glare, environmental overload, etc.

The 'Forgiving' Environment

As previously mentioned, one or more malfunctions may occur in the operation of an individual vehicle-driver unit without an accident resulting. For example, a tire could blow out (a malfunction), the vehicle begin to skid, the driver steer "away from" instead of "into" the skid (a driver decision failure), and still no additional damage or injury be produced. Thus there is a requirement that the surrounding environment has to contain some item or factor which causes the additional damage. Such factors may be other traffic, roadside furniture, utility poles, structures, ditches, embankments, etc. The presence of these items constitutes an "unforgiving" environment and their absence constitutes a "forgiving" environment.

If a malfunction which causes a disruption of the system function occurs in an "unforgiving" environment, the result is an accident. If the same malfunction occurs in a "forgiving" environment, the malfunction may become a system disruption and an inconvenience (but with no additional detrimental effects) or may not even appear to be a disruption in the system operation as a driver almost instantly corrects for the failure.

Two examples will illustrate the concept of "forgiving" and "unforgiving" environment:

1) A vehicle, being driven from a parking lot via a left turn onto a four-lane undivided highway, had a tie rod break. The vehicle was traveling slowly and was brought to a stop without further difficulty. The opposing and conflicting traffic avoided the disabled vehicle and no further damage or injury was inflicted. Thus, a vehicle malfunctioned but the environment was "forgiving" and no accident resulted.

2) A defective vehicle brake repair resulted in the loss of brake fluid so that the brakes of the subject vehicle completely failed. The driver became aware of this failure at a "forgiving" location where all evidence indicated that the vehicle could have been brought to a stop without additional damage or injury. However, the driver failed to comprehend the seriousness of the brake failure and continued to drive the vehicle. A few minutes later, and some one-half mile further along the road, this driver found herself in an "unforgiving" environment where the brake failure made an accident inevitable. Thus, the original malfunction was discovered in a "forgiving" environment but the second malfunction placed the unit in an "unforgiving" environment.

Additional examples would merely emphasize that the transition from a malfunction to an accident is some type of time-variable probability function which involves all components and elements of the system. At present it is impossible to define this function, as comparatively little is known about the malfunctions which contribute to accidents, and practically nothing is known about the malfunctions which occur without resulting in accidents. Therefore, at this time, it is only possible to recognize the importance of the environment in accident causation and to describe some of the items which constitute an "unforgiving" environment—i.e., items which decrease the "forgivingness" of a particular environment are: an increase in traffic volume, increase in poles and other roadside structures, etc.

Reduction Of Accident Frequency

The theory of accidents as presented above indicates two general methods of reducing their frequency:

1) Because an accident is a special type of disruption to the function of the transportation system, the removal of the causes of disruptions would eliminate accidents. That is, if component malfunctions or failures were prevented, then accidents and other system disruptions could not occur. Therefore, one method of reducing accidents would be to detect the malfunctions which occur in the system and take steps to avoid repetition of these failures.

2) An accident results when a malfunction occurs in an "unforgiving" environment. Therefore a second approach to accident prevention is to design the environment to be "forgiving." This is possible within certain limits—mainly economic. Various researchers have advocated, and various highway designers have used this approach in the past. Examples of improvement by this process include: expressways with wide, traversible, obstacle-free medians and shoulders; breakaway sign supports and poles; geometric designs which avoid conflicts of opposing traffic, etc. Providing a "forgiving" environment offers a dual benefit as it aids in accident prevention and also aids in lessening the severity of the accidents which do occur.

Highway Failures

Malfunctions or failures in the highway component are few and infrequent. Also, these failures are generally easy to identify and their corrections are obvious. For example, the indentification of a burned out traffic-signal light bulb requires nothing more than an observation; correction simply requires the replacement of the defective bulb; and control of conflicting traffic may be maintained during the time necessary for replacement by having two signal faces for each approach (a recommended procedure that is not always followed). Although the identification and correction of highway component failures does require some knowledge of the highway component, it does not require extensive knowledge of the other system components or the interactions between the various components.

Highway Conditions

The more difficult problems associated with the highway component concern those adverse highway conditions which require the driver to make special adjustments or modifications to his driving pattern—i.e., involve driver-highway interactions. The additional adjustments or modifications required by these conditions make the driving task more difficult and complex because the driver must receive and analyze more data, and then make and act upon a greater number of decisions.

Each additional responsibility placed on the driver increases the possibility of a driver failure which in turn increases the possibility of an accident. The identification of adverse highway conditions may be difficult because many conditions are obscure. Therefore identification often requires detailed knowledge of the interaction between the highway, driver, vehicle, and environment. One obvious method of detecting deficient highway conditions is to compare accident frequency for specific locations along the roadway. Efforts of this type are used to isolate sites for many spot improvements. Although accident frequencies may serve to isolate the locations of substandard conditions, identification of the specific condition may still be difficult. Also, many highway conditions may be so obvious that drivers are not misled and are therefore safe designs. Conversely, extremely obscure conditions may tend to "trap" even the wary and observing driver.

Accident Rates, Design Elements and Traffic Volumes

Prior to commenting upon some specific highway conditions which have been identified as contributing to the generation of accidents, a brief review of some overall accident rates for various highways and traffic volumes is in order. A few years ago, Cornell Aeronautical Laboratory undertook a study directed to relating accident rates to design elements on rural highways.[2] In the study, four roadway types dominated the data. These were: 1) the characteristic two-lane highway with no access control; 2) four-lane facilities with no median and no access control; 3) four-lane divided highways with no access control; and 4) four-lane divided highways with access control. Figure 2 shows comparative accident rates for the four types of roadway. In the figure, the abscissa is the average daily traffic and the ordinate is the annual number of accidents per 0.3 mile segment. Both are plotted to logarithmic scales. The curves on the figure reveal that controlled access highways (such as the Interstate Highway system) had accident rates which were roughly one-third of the rates of the other three types. The reasons for this difference may be explained by the design criteria which were applied to these facilities: few, if any, conflicts with opposing vehicles, increased sight distances, high standards of alignment, a more "forgiving" environment, etc. Figure 2 therefore actually reveals accident frequency differences between two standards of highway design, and indicates that accident frequency may be reduced by improved design of the physical plant. That is, high design qualities: a) reduce the number of driver decisions required which results in fewer driver failures and hence, fewer accidents and b) provides a more "forgiving" environment whereby fewer system failures become accidents. Conversely low quality design: a) provides more opportunities for driver failures and consequently more accidents and b) results in a less "forgiving" environment so that a greater percentage of the system failures become accidents.

In Figure 3 the annual number of accidents for 0.3 mile segments of two-lane highway is plotted against average daily traffic. The three curves are labeled "total," "one-vehicle," and "multi-vehicle" accidents: "one-vehicle" accidents are those occurrences in which only one motor-vehicle unit was involved, "multi-vehicle" accidents involved

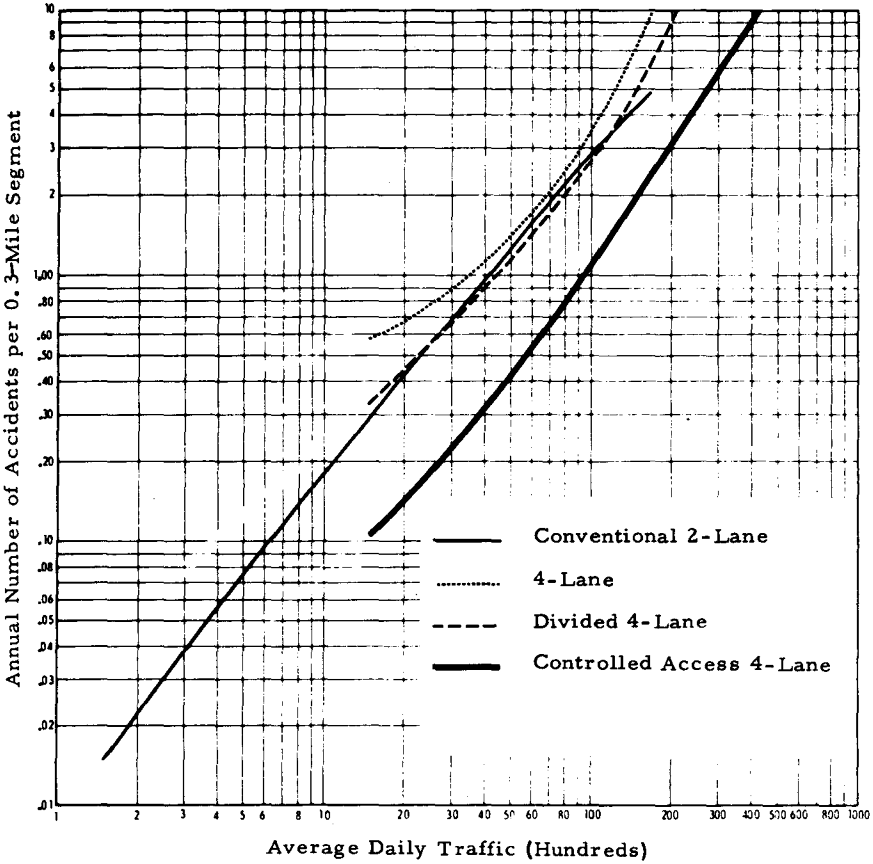

FIGURE 2. *Total Accident Rates by Type of Highway: 2-lane, 4-Lane, Divided 4-Lane, Controlled Access Divided 4-Lane*

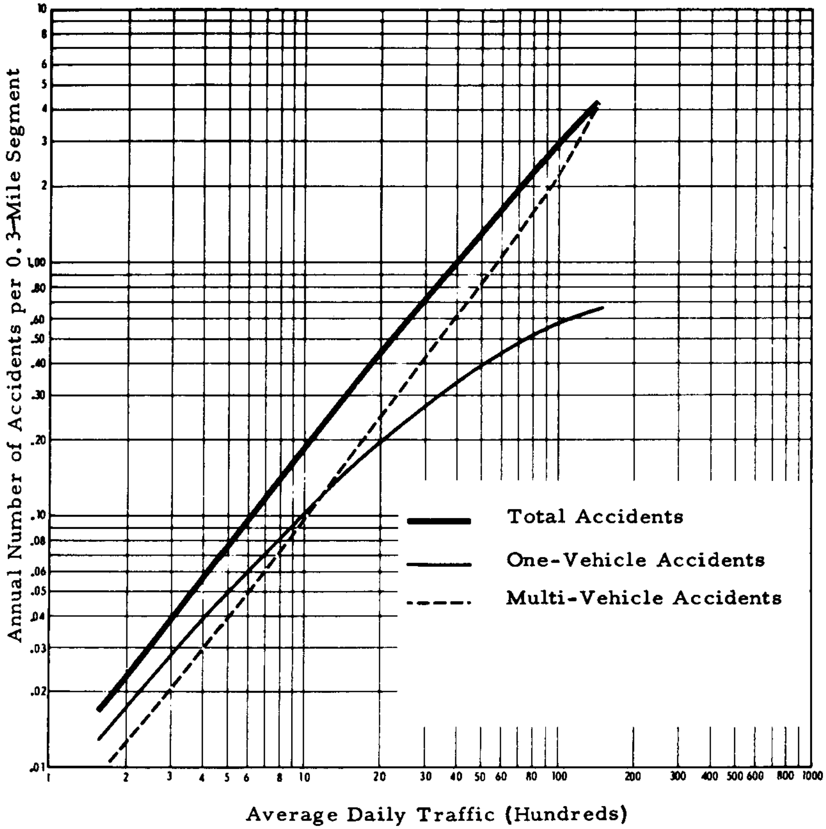

FIGURE 3. *One-Vehicle and Multi-Vehicle Accident Rates for Conventional 2-Lane Highways*

two or more units, and the "total" accident curve is the sum of the other two groups. The curve for total number of accidents is steeper than 45°, which indicates that total accidents increase more rapidly than traffic volumes.[3] This is to be expected for two reasons: a) each driver is required to make more decisions in heavy traffic volumes, and thus more failures result and b) additional traffic volumes decrease the "forgiving" environment—i.e., there are more vehicles to strike. The "forgiving" environment also explains the change in the rates of one-vehicle accidents and multi-vehicle accidents. At low traffic volumes, one-vehicle accidents constitute a high percentage of the total accidents because there are fewer conflicting vehicles, while at high traffic volumes multi-vehicle accidents dominate because there are greater numbers of conflicting vehicles.

Figure 4 visually presents the difference between the number of accidents reported on 0.3 mile segments with no geometric features ("pure" segments meaning no intersections, no structures, no gradient over 4 percent, and no curve sharper than 4°) and on segments which contain either an intersection or a structure. The segments containing intersections have an annual number of accidents approximately twice that of "pure" segments (especially true in the central ADT ranges in which areas the curves are statistically most accurate). Again this is as expected because intersections increase the number of driver decisions required and the vehicles on the intersecting road make excellent targets.

The conclusion that may be drawn from these displays is that highway design can be used to minimize the number of accidents. However, the extensive use of access control, physical separation of conflicting streams of traffic, rigid control of curves and gradient, and employment of other high quality design features would necessitate the expenditures of enormous sums of money. This would often be impractical in areas of low traffic volume and also difficult in areas requiring a high degree of freedom of movement. A more practical approach which would reduce the number of accidents while being economically feasible is to correct the major highway deficiencies which exist and to avoid repetitions of these deficiencies in future designs. This modified approach is more diffcult to accomplish because it requires an understanding of the entire highway transportation system and, in particular, requires an understanding of the driver, the driving task, and driver response to various stimuli.

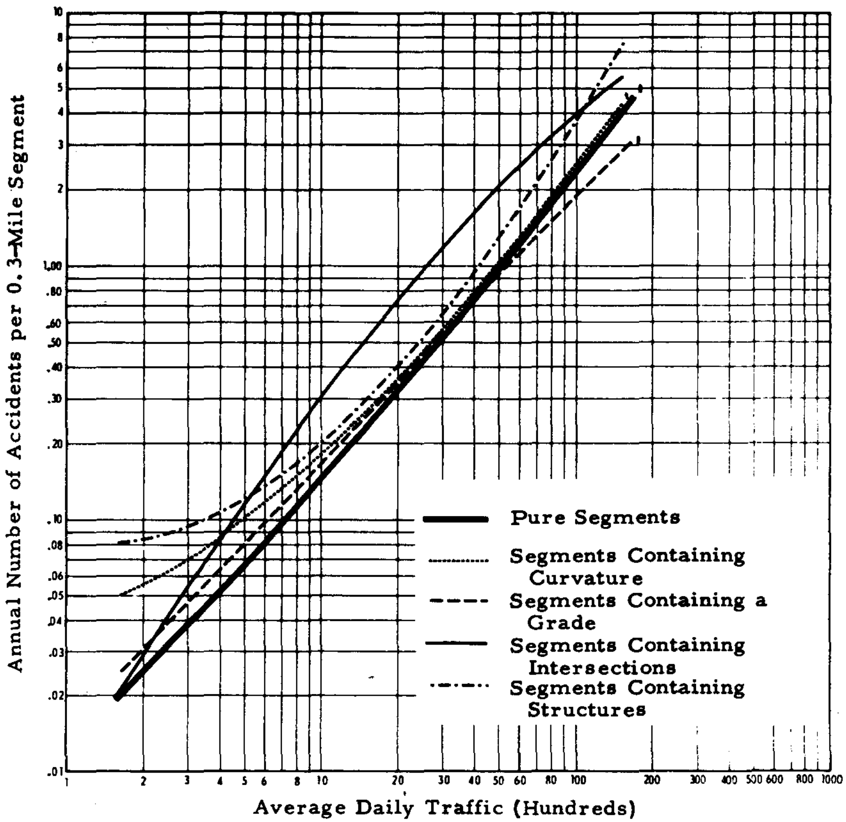

FIGURE 4. *Total Accident Rates on Conventional 2-Lane Highways with One Geometric Feature Present*

Examples of Adverse Highway Conditions

A geometric design is labeled "inadequate," "inferior," or "substandard" when the design encourages or permits drivers to be confused, misled, or misdirected. The following is an example of an inferior intersection design which exists in the immediate vicinity of CAL. This intersection has been the scene of frequent accidents of which the vast majority have similar descriptions. The plan view of the intersection is shown in Figure 5. The general description of the majority of accidents which have occurred at the location is:

> Unit #1 would be westbound in the curb lane within the tunnel approach (a three-lane facility). Unit two would be southbound on approach A with driver two intending to enter the tunnel and proceed easterly. On approach A, driver two would see the tunnel entrance from a reasonable distance but he would not be able to see the painted islands and traffic control devices until nearly to the intersection. Therefore, driver number two during a moment of being unwary and incautious, would take the direct path to the tunnel and thereby bypass the traffic control devices. The more direct movement to the tunnel entrance would place the southbound vehicle on the wrong side of the road at the tunnel entrance and directly in the path of the unit exiting from the tunnel. This approach results in direct conflicts between the two vehicles.

Not only were the actions of the drivers on approach A similar, but as a rule the drivers were comparatively unacquainted with the intersection, did not know the proposed traffic pattern, and therefore could be easily misled by the apparent line of least resistance—the direct, visible and natural path—to their immediate destination. Mention should also be made of the fact that the center lane of the tunnel is designed for reversible traffic flows and controlled by overhead traffic signal lights (a green arrow or red light above each lane). The signals over the lanes entering the tunnel are more prominent to drivers on approach A than the intersection traffic signal.

Observations reveal three highly significant deficiencies for this intersection: 1) the path intended for vehicles approaching from the north requires an unnatural movement, and the drivers are given inadequate warning of the required maneuvers; 2) the view of approach

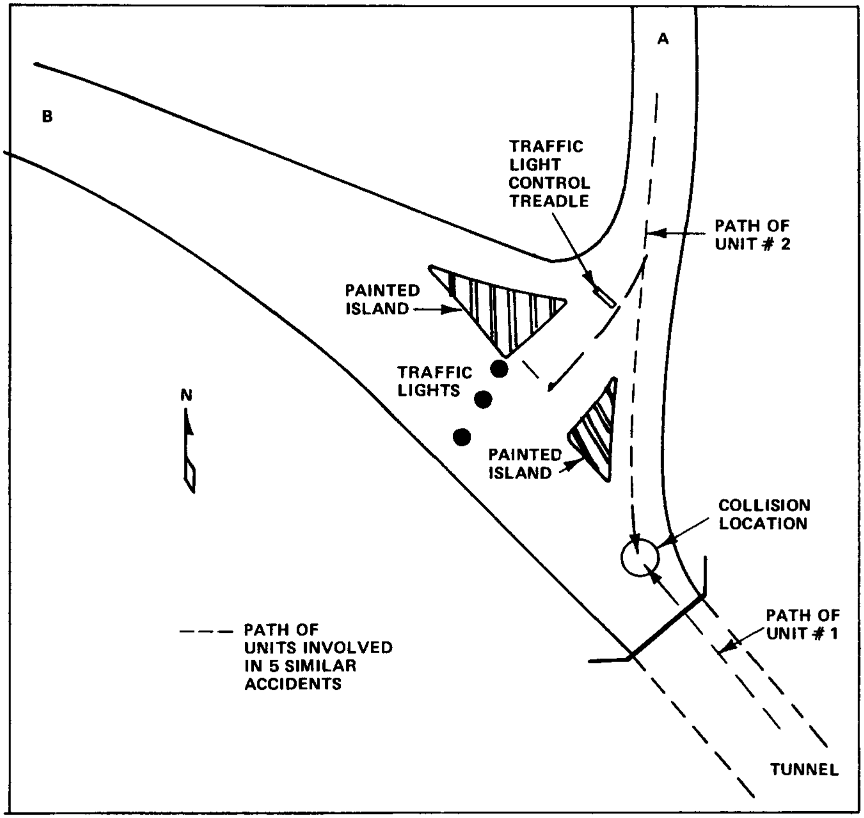

FIGURE 5. *High Accident Frequency Intersection*

A from the tunnel approach is restricted (Figure 6); and 3) the tunnel provides a vision problem as its darkness, in comparison with the surrounding terrain during the day time, limits the identification of vehicles approaching through it. These adverse highway conditions misled drivers approaching the intersection, and the deception is particularly hazardous for drivers who are unacquainted with the roadway, subjected to momentary confusion, distracted, or otherwise susceptible to being misguided on the approach.

Less obvious inferior geometric conditions are present in many facilities which are presumably of high quality design. One roadway which was the scene of several severe accidents had a compound curve designed into it. Detection of this feature was somewhat difficult because almost all drivers automatically compensated for the change in curvature without realizing why a steering correction was needed. Indeed, during good weather the condition seldom causes any driver difficulty. However, during adverse ambient conditions (such as a wet roadway and high traffic volumes), inexperienced or distracted drivers may encounter difficulties at the site. The situation develops when the driver enters the more gentle curve, establishes his steering angle, becomes concerned with some other undertaking (which may or may not be related to the driving task), fails to recognize the need to adjust his steering until too late, and then either overcompensates so that his vehicle goes into a skid or fails to compensate adequately so that his vehicle strikes the curbed median. Either alternative may be disastrous in traffic of comparatively high speed.

Unnecessary curbs may aid in generating accidents or be a part of an "unforgiving" environment. A six- or eight-inch vertical curb is inadequate to stop a vehicle that strikes it at any appreciable angle. Vehicles striking curbs at low angle of approach may be deflected out of control as the curb is struck only by the vehicle's wheels. There is also another type of accident involving certain types of curbs. These involve vehicles straddling a curbed divider (Figure 7). The curb in this case was used to separate expressway through traffic from the existing traffic (Figure 8). The involved driver became momentarily confused, decided to switch lanes too late and the result is as shown in the picture.

Another hazard of the highway is sign supports. The curbed dividers mentioned above have signs at the points where they begin, directing

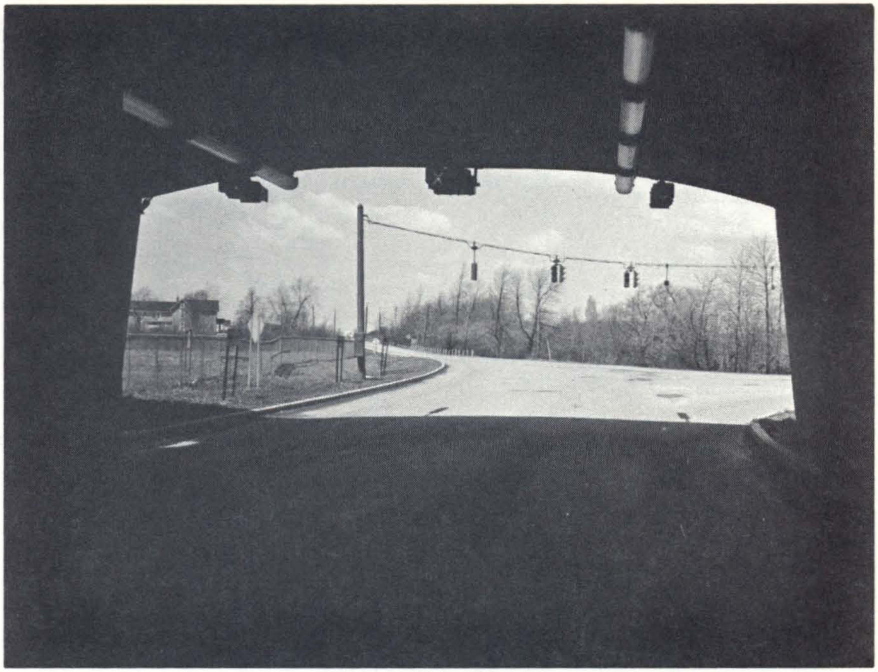

FIGURE 6. *Driver's View From Tunnel*

FIGURE 7. *Vehicle Straddling Curbed Divider*

FIGURE 8. *Curbed Divider*

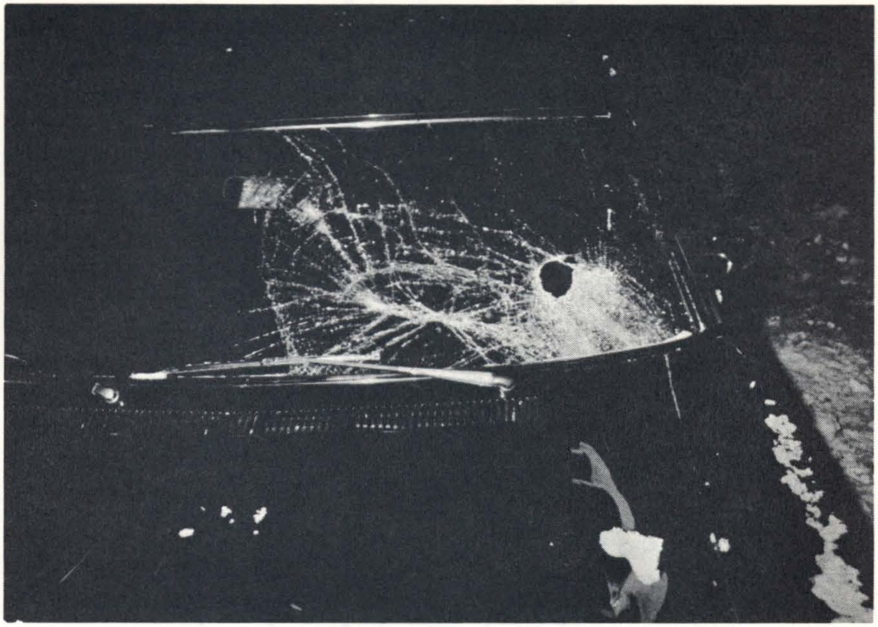

FIGURE 9. *Windshield Damage From Impact With Median Sign Post*

traffic to either side of the divider. The vehicle that straddles the divider must also hit the sign. The results of the collision between vehicle and sign are shown in Figure 9. The straight line on the windshield is from contacting the edge of the standard size sign and the hole in the windshield was caused by the small steel channel sign support which penetrated the glass as a spear. Fortunately the driver was not in the path of the projectile.

Exits from private property are scenes of numerous accidents which could be avoided by better design, zoning laws or improved driveway regulations. One type of accident which appears frequently at these locations is illustrated in Figure 10. Driver A, exiting from the driveway and desiring to turn left, is fully aware of vehicle B. Vehicle B may have a right turn indicator flashing or driver B may actually stop and wave A out into traffic. Driver A takes advantage of what appears to be an opportunity to complete his maneuver and proceeds forward into the path of vehicle C which was previously hidden from his sight behind vehicle B. Although the police easily place legal responsibility in these cases, the fact remains that design or traffic control procedures can be used to prevent many of these events. Possible solutions would include prohibiting left turns, constructing perimeter roads so that existing traffic is grouped and exits through a signal controlled intersection, or in exceptionally high traffic-volume areas an overpass or underpass may be constructed. Examples of elaborate entrances and exits may be seen at certain large shopping plazas.

Even the timing of traffic signals is an influential item in highway safety—especially the time duration of the amber phase. On a 50-mph highway, a three second amber between green and red may place a driver in an untenable position. As an example, assume that a driver traveling at approximately 50 mph (70 ft/sec) is 300 ft from an intersection when the signal changes from green to amber. There will be a short time lost while the driver is deciding what to do—a reasonable estimate is 1 second during which time he travels 70 ft. He can now activate his vehicle's brakes but must stop in less than 230 ft which requires a deceleration of some 10 1/2 ft per sec (approximately 0.33 g's). Because this deceleration is somewhat uncomfortable and undesirable, the driver may decide to continue through the intersection. However, at a speed of 70 fps he will enter the intersection some 1 1/4 seconds after the light has changed from

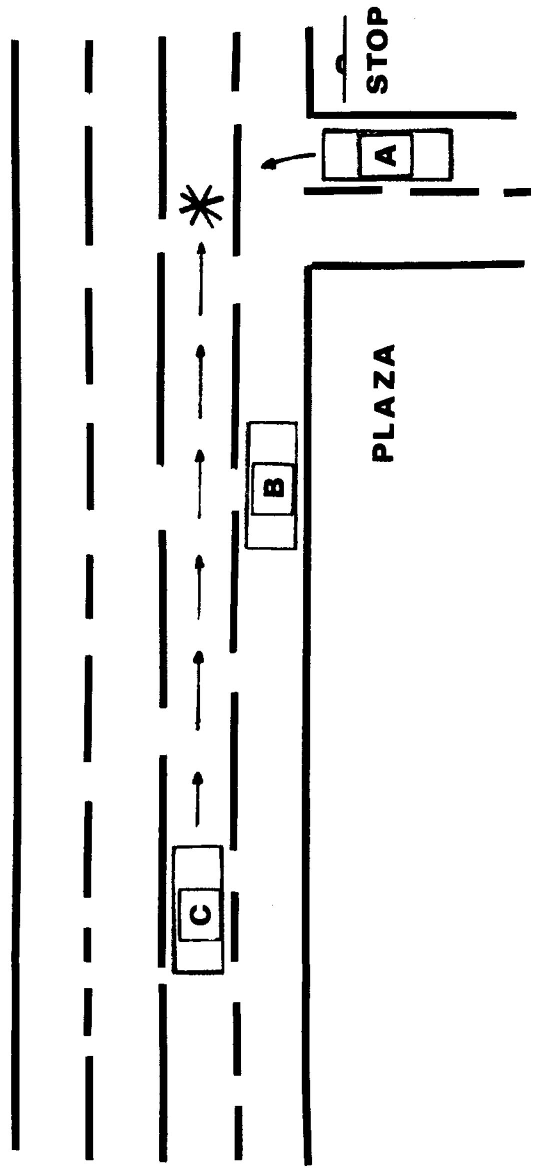

FIGURE 10. *Exit From Private Property Onto 4-Lane Highway.*

amber to red and after the opposing traffic has been released by a green light. If the drivers in the conflicting stream of traffic are alert and attentive, they will note the approaching driver's dilemma and allow him ample time to clear the intersection prior to their entering. However, one of these drivers, impatient, eager to move with the light change, and failing to check the approaching traffic, may accelerate into the intersection with, or even ahead of, the green light. Collisions are generated by such actions.

A recommended solution which reduces these collision events is to use a 3-second amber with a 1 1/2- or 2-second all-red phase. This provides for a 4 1/2- or 5-second time separation which will eliminate many of these accidents, although each intersection should be considered individually. Other accidents have occurred at intersections where traffic signals are placed improperly. In one particular case a careless driver saw the green light for traffic from the cross street, thought it was meant for him, and drove into the intersection with the opposing traffic. The signal had been hung at an angle to the intended approach and could be viewed and interpreted incorrectly.

The question, "How far should an engineer go in order to design and construct 'foolproof' highways?" is a difficult one to answer. Again a particular event which recently occurred in the Buffalo area provides a good example. The highway shown in Figure 11 appears to be one of reasonably high quality design—a four-lane expressway with a legal speed limit of 50 mph.

The median is not as wide as desired but represents a compromise between construction cost and desired width—this section of the road is cut through rock and is located in a built-up area so that both the construction of wide medians and the purchase of right-of-way would be expensive. Perhaps the most obvious defect shown in the picture is the entrance ramp and acceleration lane which are difficult for approaching drivers to see. This condition was unrelated to the subject accident.

The accident which occurred at this site was bizarre and hopefully will not be repeated. Vehicle A, traveling in the right hand lane, went onto the shoulder, just missed the rock wall and then swerved to the left across the median. As may be noted in Figure 11, the median contains a shallow ditch with comparatively gentle side slopes (the median is 28 ft wide with a depth of 28"). As the vehicle (now

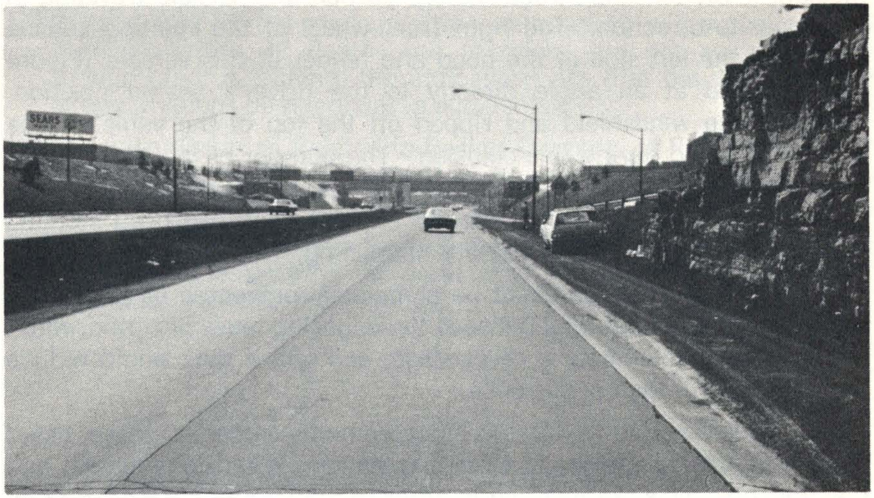

FIGURE 11. *Four-Lane Expressway*

FIGURE 12. *Passenger Car Struck by Vaulting Vehicle*

traveling sideways) emerged from the ditch on the far side of the median, it vaulted and struck the top portion of a vehicle traveling in the opposite direction. The right front wheel of the vaulting vehicle contacted the left side of the hood and fender of this vehicle (Figure 12), traveled at an angle directly to the driver's seated position, collapsed the windshield and ripped off the top of the vehicle. The driver was killed during this collision. The bumper of the vaulting car then struck a light pole some two feet above the ground, and as it slid down the pole, rotated into a second vehicle which had been stopped by its driver when she saw what was happening.

Accidents of this type could be completely prevented by constructing an insurmountable wall between the opposing lanes of traffic, wider medians would eliminate a percentage, and guard rails would reduce the frequency of their occurrence.

The consideration of design improvements such as those listed above requires an answer to a basic question: What construction and maintenance costs are justified in order to reduce the number of highway accidents and mitigate their severity? It is inconceivable to design for the elimination of all accidents as construction costs would be excessive, and success would be doubtful. Likewise, it is inconceivable that low and mediocre designs be allowed to continue to mislead, misguide, confuse, or otherwise entrap the highway user.

In summary, those involved in the design, operation, and maintenance of the physical facilities of the highway transportation system need a knowledge of the system components and the interactions of these components. Of these components, knowledge of the driver, his task, and his response to stimuli are the most essential. In addition the highway or traffic engineer must achieve a balance between costs (be they economic, esthetic, social, etc.) and the safety aspects of the facility. Only with this knowledge can the highway engineer provide facilities which properly relate to the entire highway transportation system.

FOOTNOTES

1. Components of the system often malfunction without additional damage, injury, or death, and therefore are not accidents (although proof is lacking, the indications are that the vast majority of malfunctions do not result in accidents).

2. "Accident Rates as Related to Design Elements of Rural Highways" National Cooperative Highway Research Program Report No. 47 (1968).

3. The raw data indicated a decrease in accident rates when the traffic volume became so great that freedom of movement of individual vehicles was limited.

DISCUSSION

Wesley Grigg Mullen

Dr. Mullen is Professor of Civil Engineering and Coordinator of the Highway Research Program at North Carolina State University. He brings to the position an extensive background in highway construction. For years he was with the city of New York, involved in the building of bridges and thruways. This practical experience provides a solid understanding of the kinds of questions and problems that need to be addressed in the laboratory before major highway expansion is undertaken. Dr. Mullen's research has been largely concerned with examining the properties of materials used in highway construction.

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THE EFFECTS OF ENVIRONMENT IN TERMS OF DESIGN AND MATERIALS OF CONSTRUCTION

I welcome the opportunity to discuss this fine presentation by Ken Tharp, with whom I was a graduate student at Purdue only a few years ago, or so it seems.

As a materials man, my approach is somewhat different from many here in this room. I would like to comment on two items or concepts in this paper that have struck a responsive note. The first is the effect of environment in terms of design features and the *maintenance thereof,* and the second is the effect of environment in terms of materials of construction and the *permanence thereof.*

I think that the terms *forgiving* and *unforgiving* are particularly appropriate. I believe also that design features are subject to inadvertent change through maintenance, and that, thus changed, they may contribute to accidents, particularly if a driver is not concentrating 100 percent on his driving. Let me cite a personal example. Many of our cities change streets for direction or make them one-way to implement an overall traffic movement plan. They post signs, obliterate old lines and paint new ones. A few weeks ago, I pulled onto a city street from a parking lot, traveled about a block down the street, pulled up to the center line, made a left turn signal, cleared traffic ahead and turned left. Another vehicle hit me on the left side. He was driving on a one-way street while I was driving as if I were on a two-way street. It cost me a ticket, repairs to his car, repairs to my car, and court costs. I thought I was driving prudently. What was wrong? The center line had been painted and repainted until it was a solid line; the street was unfamiliar to me, and in the absence of any stimuli other than the solid line I had driven it as a two-way street. Legally I was wrong, but I think the traffic and maintenance personnel of this particular city could have made the environment a little less unforgiving.

The second point is related somewhat to the first inasmuch as it is sometimes difficult to separate materials effects from geometric effects. However, the major concern of this second point is materials of pavement construction.

Wherever there are highways, builders and users alike are concerned with the safe passage of vehicles that are operated over them. One aspect of this safety is that there be adequate tractive or friction force developed between tire and road surface to sustain locomotion and to allow stopping within safe limits. This aspect of safety is tackled under the general designation of skid resistance.

The problem for those who design, build and maintain highways is to know enough about the factors that contribute to skid resistance to allow skid resistance to be maintained at an adequate level under all conditions of traffic and environment.

We are conducting research on our campus as part of a broad effort to treat the problems of maintaining skid resistance. This research effort includes a program for determining the wear and polishing properties of aggregates as these properties may affect skid resistance of the pavements in which they are used.[1]

Two objectives of this study have been to

1) Develop a test or tests for ranking aggregates as to skid resistance after exposure to wear and polishing, and

2) Determine the causes for different behavior of different aggregates undergoing the same tests.

To accomplish the first objective two methods were tried. One was the polishing of loose aggregates, the second was the polishing of pavement samples into which selected aggregates had been incorporated.

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[1]Support to the Highway Research Program is provided by the North Carolina State Highway Commission in cooperation with the United States Bureau of Public Roads

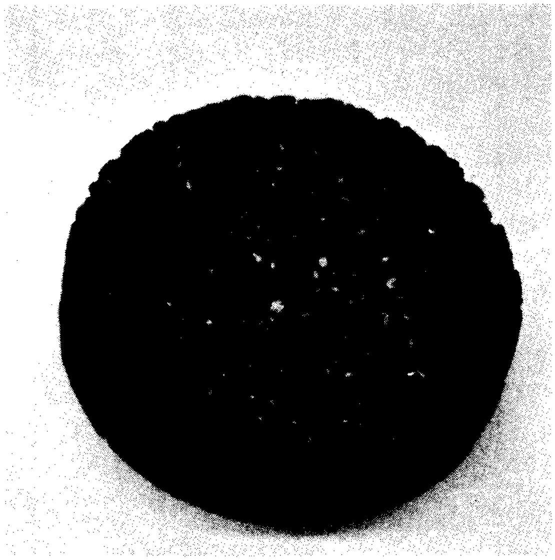

FIGURE 1. *Pavement Sample*

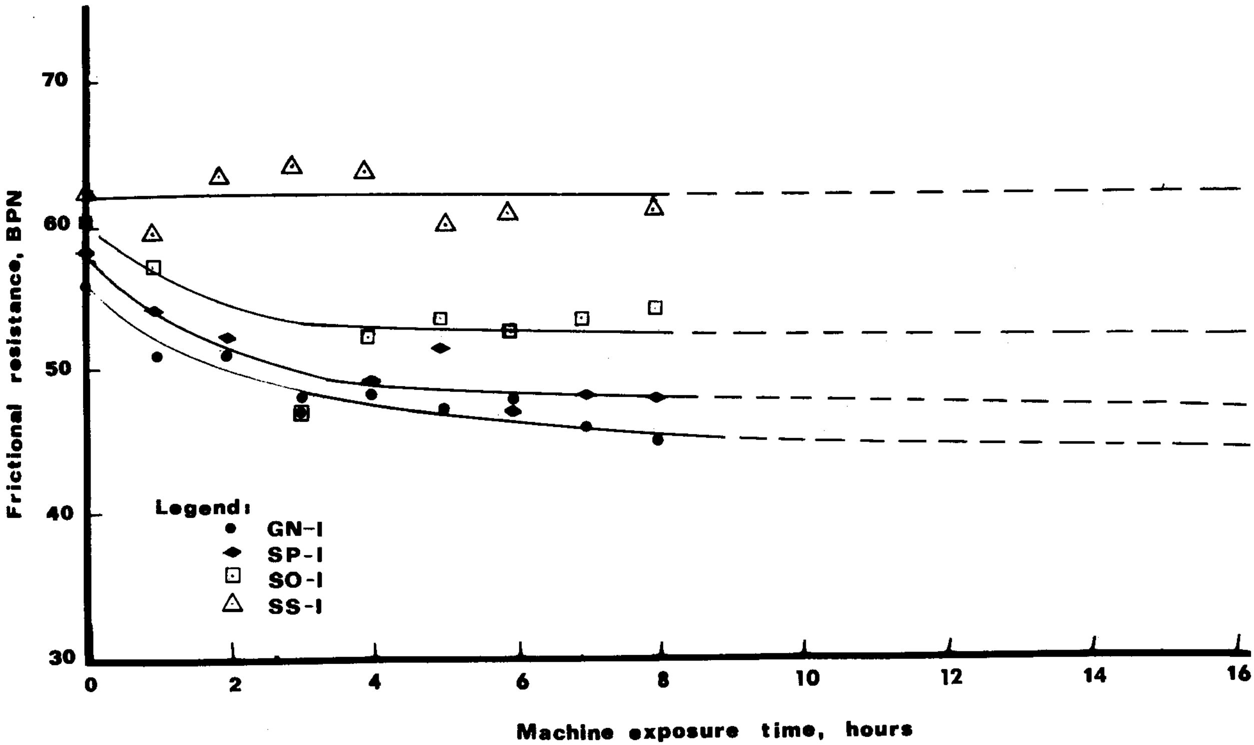

FIGURE 2. *BPN Versus Circular Track Polishing Time Curves for GN-1, SP-1, SO-1, and SS-1.*

The device used to polish loose aggregates was a jar mill charged with aggregates and flint pebbles while the pavement samples were polished in a circular test track under the action of pneumatic tires.

Here is a pavement sample used in the test track (Figure 1). This specimen is laboratory made, but 6-foot diameter cores from field pavement can be tested with equal ease. Specimen can be either bituminous or portland cement concrete.

Here is a plot of some test results from the circular track showing BPN[2] versus wearing exposure for pavements made with various aggregates (Figure 2). Note how different aggregates level off at various BPN values making it possible to differentiate between aggregates. Equivalent results have been obtained from jar mill wear tests. It remains to relate labortory results to field performance.

The second objective mentioned has involved relating petrographic properties of aggregates to skid resistance. This part of the research is not as far along as the wear tests but indications are favorable that differential hardness of mineral constituents of an aggregate is an important factor in determining the wear performance of that aggregate. Intuitively one would expect differential wear to aid in maintenance of a skid resistant surface.

Thank you Madam Chairman. Congratulations to Ken Tharp on a fine, thought-provoking paper.

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[2]British Pendulum Number—a friction coefficient measured using the British Pendulum Tester

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