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HUMAN FACTORS RESEARCH IN HIGHWAY SAFETY

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Several groups were paramount to the planning, conduct and reporting of the workshop.

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Several members of the sponsoring committees were heavily involved in workshop planning and participation and in reviewing drafts of this Circular. Patricia F. Waller, University of Michigan Transportation Research Institute, chaired this group and was Chair and Moderator of the workshop. She also gave the Keynote Address. Our special thanks to Dr. Waller for her tireless and innovative work on behalf of the human part of the highway safety equation. The other members of this group were:

R. Wade Allen, Systems Technology, Inc.
Vivek D. Bhise, Ford Motor Company
Michael Perel, National Highway Traffic Safety Administration
Thomas A. Ranney, Liberty Mutual Research Center
Thomas H. Rockwell, R & R Research, Inc.
Alison Smiley, Human Factors North, Inc.
Leslie Ann Whitaker, University of Dayton

The four break-out sessions during the second day of the workshop were ably directed by:

R. Wade Allen, Systems Technology, Inc, (Intersection crashes)
Rodger Koppa, Texas Transportation Institute, Texas A & M University System (Run-off-the-road crashes)
Thomas H. Rockwell, R & R Research, Inc. (Rear-end crashes)
Alison Smiley, Human Factors North, Inc. (Head-on crashes)

The background papers and presentations, which set an excellent stage for the technical discussions of the workshop were written by:

Kenneth Campbell, University of Michigan Transportation Research Institute
Robert Dewar, Western Ergonomics, Inc.
H. Douglas Robertson, University of North Carolina at Charlotte
Charles Zegeer, Highway Safety Research Center, University of North Carolina

Members of Science Applications International Corporation technical staff and George Mason University faculty served as recorders during the break-out sessions. Without their help, the reporting on the last workshop day and the writing of this Circular would have been impossible.

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INTRODUCTION

While human factors safety issues have long played an important role in the design, operation, and maintenance of the nation's highways and byways, current as well as planned and future developments make attention to them more essential than ever before. Recognizing and accounting for the ways drivers, roadway features, operations, and traffic control devices interact both in the planning and development of facilities and in remediative strategies and actions have become increasingly important in the Federal Highway Administration's activities. A significant portion of its annual budget is specifically allocated to these problems each year for both short-term and multiyear research projects. Sponsorship and participation in conferences and workshops that tap the expertise of engineers, researchers, and administrators involved in human factors safety issues either directly or indirectly are important parts of FHWA's planning in the area. The present report is the proceedings of one such workshop.

With the cooperation and sponsorship of FHWA, the Transportation Research Board held a workshop on Human Factors in Highway Safety in Washington, D.C. April 1-3, 1992. TRB sponsorship was provided by three committees: A3B02, Vehicle User Characteristics; A3B06, Simulation and Measurement of Vehicle and Operator Performance; and A3B08, User Information Systems. The objective of this workshop was to develop a set of prioritized research problem statements in the area of human factors highway safety that could be made available to federal and state agencies, academia, and the research community at large. More than 65 invited professionals representing a variety of disciplines and expertise from federal and state agencies, private industry/consulting, and the academic community participated in the conference.

In preparation for the workshop, four crash/accident categories were identified that account for significant loss of life or injury each year, represent areas that to date have eluded attempts at completely satisfactory design solutions and countermeasures, or have not been adequately addressed within a workshop forum in the past:

Head-On Accidents/Collisions
Rear-End Accidents/Collisions
Run-off-the-Road Accidents
Intersectional Accidents/Collisions

Since an important aim of the workshop was to focus on human factors issues that would be of special interest, significance, and relevance to the highway and traffic engineering community, a number of specialists within those areas were asked to present background papers addressing issues, concepts, terminology, perspectives, etc. with which many participants may not have been familiar. Papers on highway design (by Charles Zegeer and Forrest Council), on traffic control devices (by Robert Dewar), and on traffic operations (by Douglas Robertson) were designed to familiarize participants with, and orient them to some of the areas that are of special concern to traffic engineers in their work and planning. In addition, to provide participants with some background information not only on the accident typologies addressed in the conference but also on research in the development of accident typologies in general, Kenneth Campbell presented a paper on accident typology research. Campbell's paper and the three background papers are included in these proceedings.

Following short welcoming speeches on behalf of FHWA by Truman Mast and TRB by Richard Pain, a keynote address was delivered by Patricia Waller, Director of the University of Michigan Transportation Research Institute. The background papers were presented and participants were then assigned to one of the four break-out groups focusing on the previously mentioned crash/accident areas. On the second day of the workshop, these groups met separately to discuss their respective areas and derive research problem statements. Each group was asked to

1. identify critical research issues in their topic area;
2. develop problem statements for these issues;
3. prioritize problem statements; and
4. recommend the top-priority research projects and suggest the amount of funding and time that would be needed for each.

During discussions, guest speakers as well as selected representatives of TRB and FHWA acted as roving participants and visited and contributed to all four sessions. During the morning of Day 3, a general plenary session was held in which group leaders presented an overview of the results of their group discussions and recommendations.

Although each workshop group was asked to focus on a specific problem area, no attempt was made to force the direction of the discussions or recommendations. That is, spirited open discussions were encouraged rather than discussions and recommendations held to hard-and-fast rules. Thus, in some cases, discussions and recommendations focused on very basic issues that seemed to be prerequisites for solving problems in a variety of areas. This may be viewed as both a strength and a weakness of the structure of the break-out group format. On the other hand, specific recommendations germane to only a narrow area of concern sometimes did not emerge. However, in their place, broader and more basic needs were revealed that had relevance not only to the crash/accident typology under consideration but also to many aspects of highway safety research. No attempt was made to redirect groups when this kind of movement away from the assigned problem area occurred.

As one would expect, many Research Problem Statements (RPSs), both within and between break-out groups, overlapped to a certain extent in terms of their overall focus, their relevance to other RPSs, or both. While some attempt was made to combine those that seemed too similar to warrant a separate listing, the reader will note that a certain amount of overlap remains.

Finally, while each of the topic areas is presented in the general priority order suggested by the individual workshop sessions, the rankings reflect the biases of those present at the workshop. By the same token, the time needed to complete the research and the costs were the workshop participants' best estimates and should be considered in that light.

KEYNOTE ADDRESS

THE NEED AND POTENTIAL FOR HUMAN FACTORS RESEARCH IN HIGHWAY SAFETY

Dr. Patricia Waller, University of Michigan Transportation Research Institute

Historically we have defined transportation as the safe and efficient movement of people and goods. This traditional definition has served us well, and the system we have built on this foundation has given us the safest highway transportation, based on miles traveled, of any country in the world. Over the past thirty-five years, our Interstate highway system has transformed transportation in ways that those who cannot recall the roads prior to that time can never fully appreciate. I can remember waiting in a long line of vehicles in Georgia while another line of vehicles moved slowly, single file, from the other direction, crossing a long wooden plank bridge that sat barely above the water level over an enormous Georgia swamp. I grew up in South Florida, and it was a major accomplishment to get from there to any other state. We have much to be proud of and we have many professionals to whom we owe a debt of gratitude.

REGULATORY INCOMPATIBILITIES

Nevertheless, the highway transportation system that we designed failed to take into consideration much of the human dimension. For example, there are built-in incompatibilities. In fact, on at least two occasions the Transportation Research Board (TRB) has created a subcommittee or a task force to try to address some of these incompatibilities.

It is probably not very surprising that incompatibilities exist, when it is recognized that the three major components of the highway transportation system fall under three largely separate authorities. The highway itself has traditionally been dominated by the thinking and the standards established by the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and state highway departments. The driver, on the other hand, is under the jurisdiction of state licensing authorities, with some overall guidance (but not to the same extent as in the case of highways) from the American Association of Motor Vehicle Administrators (AAMVA). Finally, the vehicle is pretty much what the industry designs and is able to market. While we hear a great deal about vehicle regulation, there is really relatively little in comparison with the range of decisions left to the individual manufacturer. When, in response to the fuel crisis in the mid-1970s, cars became smaller and trucks became larger, the roadway was ill equipped to accommodate the new vehicle mix. The guardrail that had redirected the 4,000-pound car was likely to overturn the 2,000-pound car. It became necessary to provide a guardrail that would protect not only the smaller car but also the larger, heavier truck.

When it comes to the driver, the problems are even greater. We license persons whom the highway system does not "fit." For example, the standards for signing established by AASHTO and FHWA require 20/20 to 20/30 vision in daylight when the sign is new. Yet virtually all states license drivers who meet a criterion of 20/40 vision, and most states will license drivers with vision as poor as 20/70. And the licensing standards have to be met only at the time of licensure. In some states, after initial licensure the driver may never have to reappear. Signs may remain posted long after their visibility has greatly diminished. Yet drivers are held responsible for being able to see the sign that they may not have been able to see at the time of initial licensure!

In spite of the fact that states persist in describing a driver's license as a privilege, the Supreme Court on more than one occasion has ruled that it is very close to being in the nature of a right. States may not deny or revoke licensure without due process. Furthermore, from a much more realistic political standpoint, state legislators are very reluctant to enact measures that would result in severe restriction of one's access to the roads, and state administrators and bureaucrats are even more reluctant to use the authority they already possess in ways that might inconvenience the public -- or, worse still, offend their constituency.

Witness the fact that it took decades of effort to achieve special evaluation for licensure to operate a motorcycle on the public roads. Anyone who thinks that a regular driver's license is sufficient to qualify one to operate a motorcycle has never tried to do the latter. And it took even longer to get any special requirements placed on the license to operate a tractor-trailer. When Congress enacted legislation in 1986 that would eventually require that operators of tractor-trailers demonstrate some competence to operate such a vehicle before driving it on the public roads, something like nineteen states still had laws that allowed an applicant to take a road test in a compact car and obtain a license to operate a tractor-trailer in any state in the union. The same applicant could operate doubles in any state except Connecticut. The full implementation of the 1986 legislation is scheduled to be complete as of today, although there has been grandfathering and, in at least one state, a provision allowing the knowledge test to be handled through a take-home arrangement. You need to keep in mind that those take-home applicants will be driving through your state.

THE AGING DRIVER

The aging driver is another area where the highway transportation system has failed to address the needs of the users. Driver licensing programs, to the extent that they have been designed at all, have been designed to qualify young beginning drivers. Vehicles still do not very adequately address the needs of older drivers and passengers. Anyone who has ever tried to read the dashboard at night in a rented car while wearing bifocals knows how much attention has been paid to the older driver. And highways are designed on the basis of standards developed primarily from performance measures obtained from young men. When it comes to the older driver, I am reminded of a response I received from a student to a question on a final exam. He said, "Dr. Waller, you have opened a whole new field of ignorance to me!" That's about where we stand when it comes to how much we know versus how much we need to know about the older driver.

TRANSPORTATION IN THE LARGER SOCIAL FRAMEWORK

While it is true that our traditional view of transportation as the safe and efficient movement of people and goods has served us well in the past, it has also failed to take into account the larger social framework in which we operate. Transportation is concerned with the safe and efficient movement of people and goods, but it is much more than that. Transportation is an integral part of what we might consider access to full participation as a citizen in our society. Transportation is inextricably related to education, health care, employment, recreation, maintenance of ties with family and friends, and virtually every important dimension of what makes life worthwhile.

Back in the 1950s, when I was a clinical psychologist, the Federal government helped to fund mental health clinics across the nation. Fees were based on a sliding scale related to one's income. The underlying rationale was that mental health care should be available to everyone independent of one's ability to pay. However, it became apparent that transportation was a major barrier to the participation of some portions of the population, just as transportation is a major barrier to access to other kinds of health care, and to education, employment, and all the rest.

Our Interstate highway system was immensely successful in what it set out to achieve. At the same time, the Interstate highway system was a significant factor in the creation of some serious social problems with which we are currently grappling. We built superhighways and we manufactured and sold supervehicles. Those who had the wherewithal purchased the vehicles and used the highways and moved out. In the process we left behind an inner city population with no influence and no affluence. When those with the power and influence moved away, they took with them much of what had sustained the social support systems -- education, health care, cultural activities. These support systems deteriorated, leaving the inner city with limited access to what enables us to become fully participating members of society.

Problems that often originated in the inner city are now creeping into society as a whole. Gradually we are recognizing that they are no longer somebody else's problems. They are everybody's problems, and they are affecting virtually every aspect of our lives, including our ability to compete economically.

This workshop is not designed to address these larger issues, although they need to be addressed. Efforts are being made elsewhere to initiate a mechanism or mechanisms for considering how we might learn from the past and apply such knowledge to our future programs in transportation. The reason I raise them now is to provide a background for the deliberations of this workshop, a background that reminds us that we need to be mindful of how our activities fit into the larger picture. If we conceive of transportation as simply the safe and efficient movement of people and goods, it is easy to think simply in terms of knobs and dials and displays and how they can best be used by people very much like ourselves.

On the other hand, if we consider transportation as an essential and integral part of our total society, a dimension of our society that enables individuals to function and communities to work, then we need to take into consideration how the systems we are designing may be used by a wide variety of participants -- young, old, educated, not so educated, English-speaking and others, short, tall, fat, and thin, arthritic, distracted, motivated, disinterested, rich, poor, and so forth. We need to consider not just the system itself but its ease of understanding, its ease and cost of acquisition and maintenance, its accuracy and reliability, etc. Incidentally, I have heard nothing so far concerning the human factors issues in maintenance of the electronic equipment that will control the Intelligent Vehicle/Highway Systems, yet maintenance will become more critical than ever, in light of potential product and tort liability.

NEW TECHNOLOGIES AND THE DRIVER

In designing and evaluating new technology and new systems, we need to include the full spectrum of users. For example, using volunteers in the evaluation of our proposals is not adequate. We have to devise ways to include subjects who are more truly representative of those who will eventually be functioning on our modified highways.

The task seems overwhelming. It also means that we need to break out of our traditional ways of thinking about what we do. We need to consider how we might modify the larger system, that is, how we design access to the system. In May I presented a paper at IVHS America on the possibilities for redesigning driver preparation and driver qualification for using IVHS technology. We do not need to limit our deliberations to the status quo so far as the human element is concerned.

While it is true that the human component of the system is basically unchanged from what we were 50,000 years ago, it is also true that we are capable of learning. Every developing country witnesses a rapid drop in highway fatality rates as the users become more accustomed to the system. It has become popular in some injury control circles to assume that humans cannot be expected to change. While it is unrealistic to think that humans can compensate for every shortcoming in the system at all times, it is also the case that humans can and do learn. A former colleague of mine, on a trip to China, noted that the highway-safety experts paused and looked both ways before crossing the street. He asked whether they had engaged in such behavior as a result of genetic coding or was it possible that the human component had been modified by instruction and experience.

Anyone who has witnessed a son or daughter attempting to master the basic elements of controlling an automobile knows that the experienced driver has been modified considerably through learning. We need to keep this simple truth in mind as we consider how and when it may be appropriate to require short-term training and certification for using certain kinds of new technology.

This approach is not new. Ever so long ago, when I obtained my first driver's license, it was standard procedure for an applicant who took the road test in a vehicle with an automatic shift to have his or her license restricted to operating only vehicles with an automatic shift.

As we consider how new technology will interact with those who operate and maintain it, we need to include the highway engineer, the vehicle maintenance personnel, enforcement personnel, the court system, and all the myriad of participants in what makes our system more or less work. While this conception expands our responsibilities, it may also enhance our opportunities for success. It should give us a wider range of flexibility in how we go about solving our problems.

It will certainly tax our imagination, our ingenuity, and our expertise. One thing for sure -- it will not be boring!

SEEKING NONTRADITIONAL RESEARCH OPPORTUNITIES

As you know, this workshop is focusing on human factors research in highway safety. Traditionally we have thought of research that would be funded by the

U.S. Department of Transportation (DOT), that is, the National Highway Traffic Safety Administration (NHTSA) or the Federal Highway Administration (FHWA). However, we should not limit our thinking to the kinds of research that they might fund. Research needs may be identified that many appear to be more fundamental than those NHTSA or FHWA has previously been willing to consider. Nevertheless, we should not ignore such research issues if we agree that they are truly essential. On the one hand, we may be able to persuade DOT that they should and could fund such research. Failing that approach, if the research is critical to what we need to know, then we need to look elsewhere for funding. We cannot allow the constraints that have existed in the past to limit what we can do in the future. If we are to be truly competitive in a world market, we are going to have to do some things that will be radical departures from past practices. The field is desperately in need of new and innovative thinking and approaches. If we restrict ourselves to simply doing more of the same, we are, in effect, conceding defeat before we even begin. So, do not limit yourselves to whatever you think might be feasible based on past experience. Instead, remove traditional constraints and focus completely on what you see as the real information needs, be they methodological, theoretical, basic information on decision making, cognition, learning, or whatever else. This is not the time to hold back. Rather, it is an opportunity to plow new ground, fire new gray cells, and kindle new possibilities.

There has never been a more exciting time to be in this field, and there has never been a time when there has been greater awareness and appreciation of the critical need for the participation of this group of experts.

BACKGROUND PAPERS

HIGHWAY ISSUES AND HUMAN FACTORS KNOWLEDGE GAPS FROM THE ENGINEERING PERSPECTIVE

Traffic Operations, Highway Safety, and Human Factors

Dr. H. Douglas Robertson, University of North Carolina-Charlotte

INTRODUCTION

Traffic engineering is concerned with the safe and efficient movement of people and goods on streets and highways. Traffic operations is the subset of traffic engineering that establishes the procedures that yield the movement of people and goods. The goal of traffic operations is to make those movements as efficient and safe as possible.

Traffic operations take place on streets and highways; thus there is a direct and important link between highway design and traffic operations. Facilities are designed to operate under specified conditions and within certain constraints. In order to operate, the system must exert some level of control; therefore, traffic control devices (TCDs) become important tools to the operator. The improper use of TCDs can have a serious adverse effect on traffic operations.

Perhaps the most challenging aspect of traffic operations is the human factor. While highway design features and TCDs are fixed or operate within a controlled set of parameters, the range of human (highway user) operating characteristics is enormous, diverse, and constantly changing. In other words, each driver and pedestrian represents a powerful, independently operating "computer" capable of sensing and analyzing information and making decisions. The presence of such power provides a tremendous resource for meeting our mobility demands if it can be directed and coordinated for the collective good of all traffic system users. Such a task is very difficult and complex because these "computers" often have limited communication abilities and skills, a diverse knowledge and understanding of the operating rules, and a unique ability to reason illogically, not to mention the compounding effect of human feelings and emotions.

This paper attempts to explain how the traffic operator currently aspires to the goal of safely and efficiently moving traffic. It also offers some thoughts about areas for further human factors research.

THE TRAFFIC OPERATIONS FRAMEWORK

Traffic operations takes a given highway system, integrates the travel demands placed on that system, and produces a system level of performance reflected by appropriate measures of effectiveness (MOE's). Each component of this simple framework is discussed briefly below.

The Highway System

The driver, vehicle, and roadway have from the earliest days of traffic engineering been the basic components of the highway system. In modern times, we have expanded the definition and description of the traditional trilogy. "Drivers" are now referred to as "users." These users include motor vehicle operators, motorcyclists, bicyclists, pedestrians, and vehicle passengers. They are collectively the human factor with whom the traffic operator must deal and serve.

The term "vehicles" has not changed over the years; however, the characteristics of highway vehicles have changed considerably. For example, automobiles have become smaller, trucks have become larger and heavier, and the engines in both have become more powerful. In the future, we expect our vehicles to be smarter, as Intelligent Vehicle/Highway Systems (IVHS) are developed and implemented.

The term "roadway" has always included not only the road, but also the environment surrounding it. The physical facility consists of lanes, ramps, shoulders, medians, sidewalks, paths, and roadside features, such as barriers, curbs, trees, and poles. It may be straight or curved, flat or hilly. It may be separated from other roads or share space with them at points of crossing. The environment includes the weather, lighting conditions, road surface conditions, and the type of land use adjacent to the facility.

Travel Demand

The principal function of a highway system is to service the travel demand placed on that system. Travel demand is created by "trip generators," i.e., places where people want to go. Trip generators may be categorized simply as home or as places for working, shopping, or recreation. The traffic operator must be able to estimate the impact of existing trip generators and be able to reasonably forecast the impact of future generators. The impacts are specified in terms of how many trips the generator will attract and when those trips will be made.

A second aspect of travel demand is a thorough understanding of the characteristics of the trips taken. Attributes of trip making include trip purpose, type of vehicle, age and experience of user, time period of the trip, distance traveled, and route selected. It is the composite of these characteristics for a particular roadway segment, intersection or network of streets that is of interest to the traffic operator. This composite is reflected as a "traffic pattern" when viewed for specified time periods. Time periods are commonly defined as morning peak, afternoon peak, off-peak, and special event. Traffic operations and controls are implemented in response to the traffic patterns that exist during specified time periods.

System Performance

The bottom line for a highway system is how well it performs in meeting the travel demands placed on it. Users of the system expect safe and convenient mobility free of congestion. That is a tall order for the traffic operator, who must meet that expectation with the system that transportation planners and highway designers have provided. Mobility, safety, and convenience are the goals in traffic operations. To determine how well those goals are achieved, traffic operators rely on MOEs.

The performance of a highway facility is measured against the "capacity" of the facility. Capacity is the maximum rate at which users can reasonably expect to pass a point or section of road under prevailing roadway, traffic, and control conditions. "Level of service" is a qualitative measure that describes operational conditions within a traffic stream and their perception by highway users. The description of operational conditions takes into account such factors as speed, travel time, freedom to maneuver, traffic interruptions, comfort, convenience, and safety. Other MOEs include accidents, delay, and user complaints.

FUNDAMENTALS OF TRAFFIC FLOW

Highway planners, designers, operators, and researchers should have a basic knowledge of traffic flow fundamentals. Important flow characteristics include speed, volume, density, headway, time-space trajectories, and delay. Several important analytical techniques are employed to assist in understanding the complexities of traffic flow. They include supply-and-demand modeling, capacity analysis, traffic stream modeling, shock wave analysis, simulation modeling, and queuing analysis. Traffic flow may be categorized as either uninterrupted or interrupted. These two terms describe the type of facility, not the quality of traffic flow at any given time. Each category is discussed briefly.

Uninterrupted Flow

Traffic conditions on uninterrupted flow facilities result from the interactions among vehicles in the traffic stream and between vehicles and the geometric and environmental characteristics of the facility. There are no fixed elements, like traffic signals or stop signs, to interrupt the flow of traffic. Freeways and highway segments between intersections are considered uninterrupted flow facilities.

The operational state of a traffic stream is defined by three measures: speed, rate of flow, and density. Speed is the rate of motion of vehicles expressed as distance per unit of time, usually miles per hour. The speed measure used for a traffic stream is average travel speed. Rate of flow is a measure of the amount of traffic passing a point in a given time period. The term "volume" is used to mean the actual number of vehicles observed, whereas, "flow rate" is found by taking the number of vehicles observed in a sub-hourly period and dividing it by the time (in hours) over which the vehicles were observed. The common unit for volumes and flow rates is vehicles per hour. Density is defined as the number of vehicles occupying a given length of road averaged over time. The common unit for density is vehicles per mile. It is an important parameter in traffic operations because it reflects the freedom to maneuver within the traffic stream.

The relationship among the parameters speed, flow, and density is fundamental to the theory of uninterrupted flow.

FLOW = SPEED x DENSITY

The general form of the relationships of these parameters one to the other is shown in Figure 1. Note that when there are no vehicles, density and flow are zero. When density increases to the point that all vehicles must stop, flow is also zero. Between these two extremes, a maximizing effect occurs that defines the capacity of the facility. As capacity is approached, available gaps in the traffic stream are fewer, speed declines precipitously, and flow becomes unstable. Unstable conditions exist on the entire high-density, low-speed side of the curves representing forced or breakdown flow. Stable flows exist on the low-density, high-speed side of the curves. The necessity of maintaining traffic operations at or below capacity is graphically illustrated.

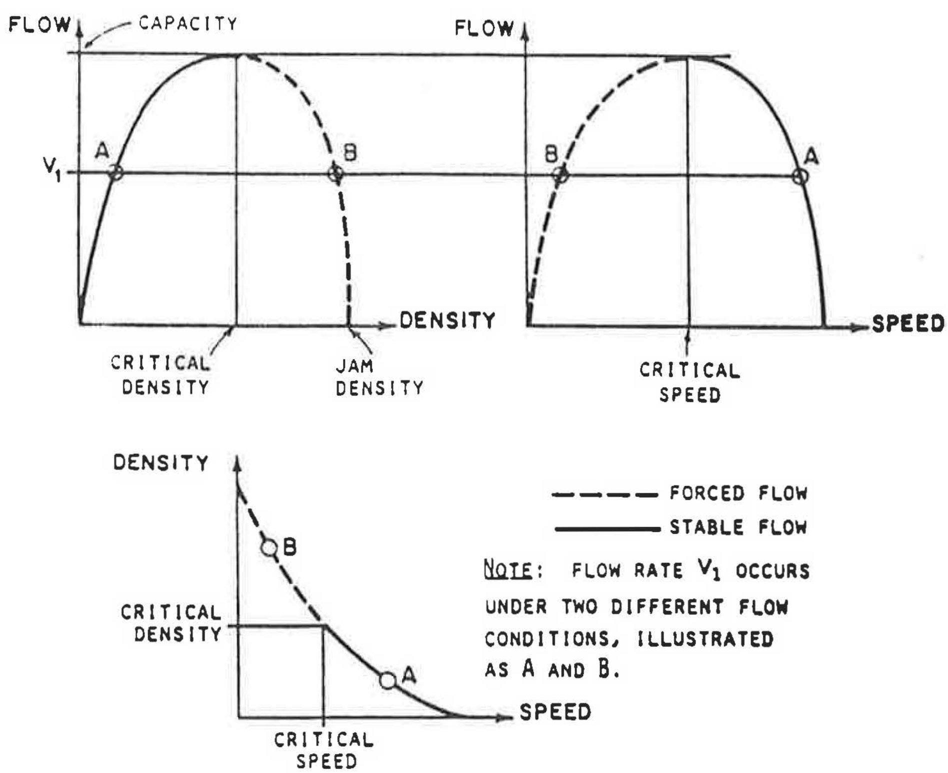

Figure 1. Relationships among speed, density, and rate of flow on uninterrupted flow facilities.

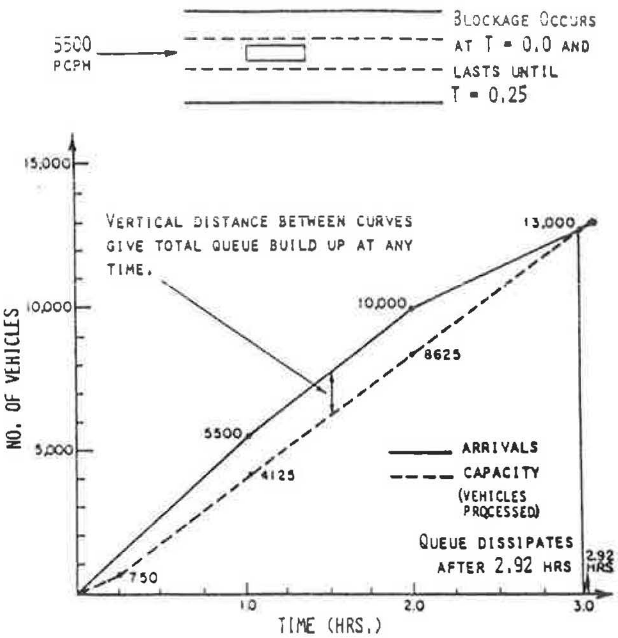

Figure 2. Effects of breakdown illustrated.

Flow breakdowns occur not only when capacity is exceeded by demand volumes but also when constrictions, either permanent or temporary, are encountered on a facility. These "bottlenecks" may be caused by a physical narrowing of the roadway, restrictive curvature, or the occurrence of an "incident," i.e., a disabled vehicle or accident. The impact of blocking one of three lanes on a freeway segment for 15 minutes is illustrated in Figure 2. With the capacity of this segment reduced by at least one-third, the near-capacity demand quickly creates queuing that takes nearly three hours to dissipate.

Interrupted Flow

Fixed elements that cause periodic interruptions to traffic flow characterize interrupted flow facilities. These elements are usually in the form of traffic signals, stop signs, or yield signs. Facilities classed as interrupted flow include signalized and unsignalized intersections, arterials with signals spaced less than two miles apart, and pedestrian and transit flows. These facilities operate by allowing the users to share time and space. Interrupted flow is far more complicated than uninterrupted flow. The traffic operator must ensure that conflicting movements are avoided and at the same time maintain a reasonable level of efficiency. Traffic control devices are the primary tools used to this end. Traffic signals are the most restrictive of these devices, yet provide the most positive form of control. Advances in traffic signal control techniques and equipment, when properly deployed, have increased the responsiveness of the signals to actual traffic demands, thus raising the efficiency of operations at the intersection.

Since flow in each movement or set of nonconflicting movements is halted periodically, attention is focused on the amount of "effective green" time that can be safely provided. Ideally, we would like vehicles to move through the intersection in a stable moving queue with uniform headways from the beginning to the end of the displayed green for that movement. Such a rate of flow for one hour of uninterrupted green time is known as the "saturation flow rate." The headway at this flow rate is called the saturation headway.

In reality, flow in any movement is halted periodically and must therefore start up again. The first driver in the queue must observe and react to the signal's changing to green, release the brake, and accelerate through the intersection. This reaction and acceleration

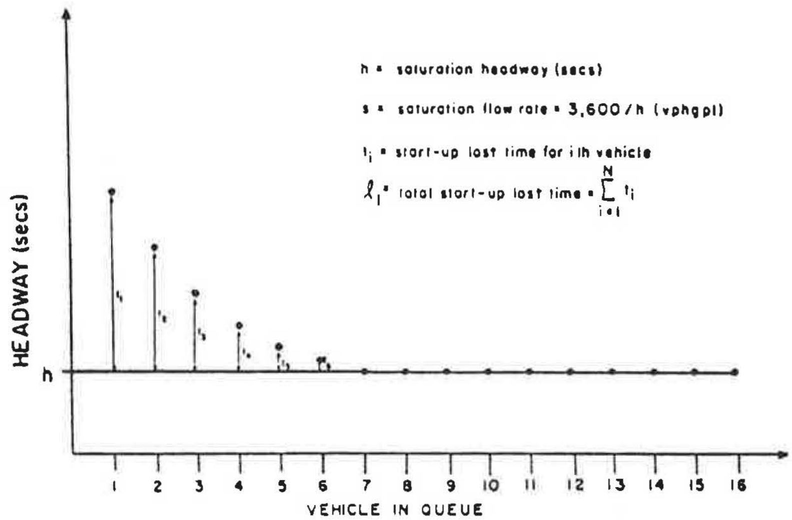

Figure 3. Saturated flow rate and lost time.

time is longer than the saturation headway. The second driver follows the same procedure, but part of his or her reaction and acceleration time occurs simultaneously with that of the first driver, so it is a bit shorter. Similarly, the rest of the queue follows suit until vehicles are once again moving through the intersection at saturation headways. Field observations show that saturation headways are usually reached after the sixth vehicle on average. The time spent getting the queue under way is known as "start-up lost time" and is depicted graphically in Figure 3.

Time is also lost when a stream of vehicles is stopped. Safety requires that some clearance time be allowed before a conflicting movement is released. Although in practice drivers use part of the displayed clearance interval, they rarely use it all. The unused portion of the clearance interval is known as "clearance lost time." Therefore, "effective green" is the displayed green plus clearance interval minus the sum of the lost time.

The amount of lost time obviously affects capacity. Each time a movement is stopped, lost time is incurred and capacity is reduced. Increasing the cycle length, and thus the time between stops, increases capacity up to a point. Other factors, such as overflowing left-turn storage lanes that block through lanes, enter the picture. Average stopped-time delay per vehicle tends to increase when cycle length is increased, and saturation headway has been observed to increase when the continuous greens have become too long.

At unsignalized intersections, the key ingredient to safe and efficient operations is driver judgment in the proper section of a gap to enter the traffic stream or cross the intersection. Gap acceptance characteristics depend on the type of maneuver to be executed, the width of the street to be crossed, the speed of approaching traffic, sight distances, time waiting, and the individual physical abilities of the driver.

TRAFFIC OPERATIONS TOOLS

Highway mobility and safety are a function of how well we manage four elements of the transportation system. Those elements are supply, demand, land use, and the institutional and funding framework. Traffic operations is certainly affected by land use, funding, and institutional constraints. However, the traffic engineer is principally in the supply-and-demand end of the business; supply deals with providing more capacity, while demand centers on reducing the numbers of vehicles in the system during periods of congestion. A number of tools are available to assist the traffic operator in these tasks.

Tools To Increase Capacity

The most obvious ways to increase capacity are to build more roads, to make the existing roads bigger, or both. In other words, the physical space is increased so that more vehicles can be accommodated. This solution has been used extensively in the United States. It will continue to be used in the future but to a lesser degree. First, it is very expensive. Second, we are running out of space on which to build or expand.

In cases where building new roads or improving existing roads is possible, care must be taken to provide adequate geometric design to meet the needs of both present and future user populations. Our population is aging and attention must be focused on providing future roads and road improvements for future users. Safety during construction has drawn a lot of attention since the mid-70's and continues to require vigilance in providing well-marked, safe paths through work zones. Access control and management are critical on future roads. Mobility and access are competing entities, whereas increasing one decreases the other, and vice versa. A clear statement of the purpose for a facility should lead to the appropriate mix of mobility and access.

Because of our seeming inability to manage growth and the increasing physical and funding constraints facing new road building, attention has turned to traffic management. How can we get more capacity out of existing systems? For many years, a number of techniques have been used to increase capacity and flow on streets and highways. We have provided or designated special lanes on urban freeways for high occupancy vehicles or trucks only. Freeway surveillance has been used on many of our systems. Ramp metering has improved flow on freeways by controlling the input of traffic into the traffic stream so that turbulence is reduced at on-ramps. Motorist information systems in the form of changeable message signs and radio broadcasts have been used to inform drivers of conditions on the freeway to aid the drivers in choosing times and routes for their trips. On arterial and local streets, we have used intersection geometric improvements, turn prohibitions, one-way streets, reversible lanes, improved traffic control devices, parking management, traffic signal improvements, and goods movement management.

More recently, we have instituted improved freeway surveillance and control systems and integrated incident management systems with them to speed up detection, response, and removal of disabled vehicles and accidents. On some freeway facilities, lanes are being added by restriping without widening the freeway. Computerized signal systems are being used increasingly on arterials and street networks. Arterial surveillance and management are being used in a few areas. Traffic signal controllers and vehicle detection devices are becoming more sophisticated and efficient. Efforts are being made to improve transit operations. Left-turning traffic has always posed a challenge to efficient operation of an intersection. Some cities are now using dual left-turn lanes to better handle heavy turning movements.

While traffic management strategies and techniques usually result in improved flow, the infrastructure must be maintained in a serviceable condition if sustained increases in capacity are to be realized. So, while physical facility expansion is decreasing, the need for maintenance is increasing. And as traffic control becomes more sophisticated, it must be designed so that people will accept, understand, and respond to the devices and techniques in a way that results in meeting the users' needs for safety, mobility, comfort, and convenience.

Tools To Control Demand

The other side of increasing supply is reducing demand. There are three ways to approach reducing demand. The first is to reduce the magnitude of the demand. We commonly measure travel demand in terms of some combination of number of trips and trip length and express it as person miles (or vehicle miles) traveled. Shorter work weeks, shorter average trip lengths, and more work at home are ways that reduce overall travel demand. The shorter work week implies a longer work day, which tends to shift the demand pattern on work days. Even if everyone traveled one day a week less, there would still be one or more days when everyone traveled to work; thus the "design" demand may not change. This approach might work better when applied in combination with some of the other approaches.

Shorter work trips occur when the worker and the job site are located closer to one another. The movement of jobs from large cities to smaller decentralized locations has generally reduced trip lengths. The efforts of workers to seek homes closer to their workplace and shopping have also reduced trip lengths. The great movement to the suburbs that has occurred over the past 30 years has changed the pattern of commuter travel. Suburb-to-suburb travel is now twice that of the traditional suburb-to-center city travel. If suburb-to-suburb trips are shorter than the old Central Business

District (CBD) trips, we are reducing demand. If not, the problem continues to grow.

The idea of working at home through the advent of telecommunications is still not a reality. Less than one percent of the work force actually works at home. The larger impact that tele-communications has had on travel is the decentralization of businesses, one reason for the movement of jobs from the central city to the suburbs.

A second approach to reducing demand is to repackage it. This is accomplished by encouraging higher vehicle occupancies and by increasing transit ridership. In short, more people are put into fewer vehicles. Techniques have included high-occupancy-vehicle lanes and programs to encourage carpooling, vanpooling lots park-and-ride lots, express buses, and transit rider incentives. Restricted parking and automobile access are being employed in some areas. Congestion-road pricing is being explored to increase ridesharing and transit use.

The third approach to reducing demand is to shift the temporal distribution of the demand. In most congested areas, the problem is too much demand for given periods of the day, the "peak periods." If the peak periods could be spread out over a longer time, there would be less demand on the system at any given time. This shifting can be accomplished by staggered work hour and variable work hour programs. In recent years, we have seen many businesses provide flex-time or extend their operating hours outside the traditional work-day hours. Even if businesses are willing to adopt these programs, it is very difficult to coordinate among workplaces to gain efficiency in spreading the demand. These methods for shifting demand may be more effective when combined with shorter work weeks.

INTELLIGENT VEHICLE/HIGHWAY SYSTEMS

Much attention has been focused recently on high-technology communications and computing systems applications to moving traffic safely and more efficiently. Smart cars operating on smart highways offers potential relief from the problems of urban congestion. While optimism abounds about the potential of IVHS, the extent of the actual impact has yet to be determined. However, IVHS offers a promising approach to developing devices and techniques that will aid the traffic operator in the quest to increase capacity and reduce demand.

There is much that technology may be able to do to make vehicles safer and to better enable drivers to avoid accidents. Examples of these technologies include radar braking, in-vehicle navigation, night vision enhancement, heads-up displays, and even longitudinal and lateral vehicle control.

Outside the vehicle we envision advanced traffic management and traveler information systems. Research is under way to develop and test integrated freeway and arterial network surveillance and control systems. The use of "probe" vehicles in the traffic stream could provide traffic condition information to traffic control centers and allow for more responsive or even predictive traffic control patterns to be used as needed. Real-time information systems would alert travelers at home or work or in their vehicles to traffic conditions on their intended routes with advice on how best to avoid delays. In the distant future, we may even see automated highways that allow close headways at high speeds.

HUMAN FACTORS RESEARCH ISSUES

Whatever the future may hold, there are many human factors issues in the field of traffic operations that need attention. While IVHS constitutes a major subject for human factors and the interface required between people and these systems, there are many questions yet to be answered about the effective and efficient use of many of our present-day traffic operations techniques. The following is a listing of some of these questions. They are in no particular order as to importance.

1. Driver Attention in Congested Traffic Situations. As traffic flow nears capacity and vehicles move closer together, drivers are required to increase their vigilance and pay closer attention to conditions around them. How can this level of awareness be achieved and maintained? What is the driver's learning curve as he or she becomes acclimated to congested conditions?
2. Rubbernecking. Incidents in the form of breakdowns or accidents cause delays to traffic moving in the direction of lanes that are blocked or restricted. These situations are handled by quick response and removal of the incident. The part of the problem that is not being addressed concerns the slowing down of traffic moving in the opposite direction where no blockage or lane restriction exists, i.e., rubbernecking. People are curious and want to see what happened. In some cases, the distraction of the incident has resulted in an accident on the free-flowing side of the highway. How can this natural curiosity be satisfied without disrupting the smooth flow of traffic past an incident?

3. Turning Movements at Intersections. The execution of a turning movement at an intersection can be a complex and taxing maneuver for many drivers, particularly older drivers. Several aspects of executing turning movements deserve attention. At multilane signalized intersections where turning movements are protected by the signal phase, the proper selection of the lane to turn into is a problem for many drivers. This problem is compounded at intersections with dual left-turns. Older drivers seem to have difficulty executing a turning maneuver alongside another vehicle. Drivers of all ages exhibit difficulty with maintaining the proper lane upon completing the turn. At intersections unprotected by signals, drivers misjudge the speed of oncoming vehicles when executing their turns. How can turning movements at intersections be made safer?
4. Car-Following Behavior. The traffic operator seeks smoothness of flow in the traffic stream. Reliance is placed on drivers to adjust their speed and following distance to suit prevailing conditions and situations. How can drivers better learn and be motivated to execute safe following distances and speeds?
5. The Impacts of IVHS Technologies on Highway Users. Almost every conceived technique requires interface with the users. Many systems are designed to reduce the information load on the driver. Other systems may result in overloading or distracting the driver with information. Traffic control systems external to the vehicle must be understood by users so that they can make decisions that will enhance the operation of the total system. How can human factors involvement in the design and operation of IVHS systems alleviate these problems?

SUMMARY

Traffic operations, highway design, traffic control devices, safety and human factors are intricately linked. The safe and efficient operation of our highway systems requires that these components be fully integrated and mutually supportive. We must seek ways to build our systems so that they take advantage of the collective mental power of the systems users and serve the mobility needs of our society.

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Traffic Control Devices, Highway Safety, and Human Factors

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INTRODUCTION

The control of roadway traffic is essential to the safe and efficient movement of vehicles and pedestrians. It traditionally has been the domain of the traffic engineer, but human factors has come to play an increasing part in the design and use of traffic control devices (TCDs) over the past three decades. The need to know about drivers' limitations in information processing and behavior as these relate to traffic control will be examined, a brief review of some relevant literature presented, and future research needs identified.

The driving task can be broken down into three main components: control (driver interaction with the vehicle in terms of speed and direction), guidance (maintenance of a safe speed and path by keeping the vehicle in the proper place in the lane), and navigation (executing a trip from one location to another). Much of the driver information necessary for the last two of these comes from TCDs. This way of looking at the driving task is the basis for the positive guidance approach (Alexander and Lunenfeld 1975).

Several criteria must be met for a TCD to be effective. Initially, it must command attention or be easily detected by the person who needs the information. It must be legible at the appropriate distance (in time to take the necessary action) and must often be legible when seen for a very brief time - glance legibility. At busy urban locations, TCDs can easily be hidden by large vehicles and seen only briefly. The device should also be quickly understood, as drivers often have only a second or two to interpret and respond to the message.

The relative importance of these various design criteria has never been established. They are not all of equal importance and can be in conflict. In an attempt to determine the relative weighting that ought to be attributed to the main criteria for traffic sign symbols Dewar (1988) solicited the views of sign experts in four countries (Australia, Canada, New Zealand, and the United States). There was widespread agreement that comprehension was most important, followed by conspicuity, reaction time, and legibility distance (the last two being similar in importance).

Evidence that decisions about TCDs in the U.S. Manual on Uniform Traffic Control Devices have typically been based largely on subjective judgment has been presented by Shapiro et al. (1987). They examined the research basis for standards in the manual. In all, 90 standards (including 44 for signs) were examined, using 3288 "potentially useful" references. They found little objective support for most of the TCDs in the MUTCD.

DRIVER CHARACTERISTICS

A great many human characteristics and individual differences influence the ability of drivers to obtain information from TCDs. In order to appreciate these, the concept of the "design driver" needs to be introduced. The question is, How will those who design and implement signs take into account driver abilities and limitations? Human factors knowledge about driver abilities is essential to decisions about issues such as color and shape codes, size and style of alphanumeric characters, understanding of symbols, legibility of signs, conspicuity of all TCDs, speed of response to TCDs, effects of environmental conditions such as darkness, individual differences (e.g., age), and information overload. These issues are the domain of the human factors psychologist or engineer. In spite of the considerable amount of research that has been done on these topics, some of which is outlined in the Driver Performance Data Book (Henderson 1987), little of it has been successfully applied to the design and use of TCDs. More detailed accounts are available elsewhere of human factors research on driver characteristics (Dewar 1992; Evans 1991) and traffic signs (Dewar 1989). A good summary of traffic engineering practice related to TCDs in general can be found in the latest edition of the Traffic Engineering Handbook (Pline, 1992).

The problems faced by older drivers as related to TCDs have been outlined by Staplin, et al. (1989) in a review of older drivers' capacities and their implications for TCD design and use. These could serve as a starting point in defining the design driver mentioned earlier.

In designing any aspect of the transportation system, it is essential to cater to the needs and limitations of the older drivers, as they have disproportionate difficulty driving at night due to a number of factors - reduced acuity; poor contrast sensitivity; lower amount of light getting into the eye of older persons; higher degree of glare sensitivity and slower recovery from glare due to headlights, advertising signs, and street lights; poorer perception of color. In addition, elderly drivers often experience more stress than do others, thus reducing the amount of attention they can devote to detecting, reading, and responding to TCDs. Speed of eye movement and visual scanning behavior also deteriorate with age. The best source of information on older drivers is TRB Special Report 218 (1988).

DRIVER INFORMATION PROCESSING AND OVERLOAD

The importance of attention in driving has been documented by in-depth accident analyses showing that difficulties with perception, attention, distraction, etc. are major human causes in over 40% of traffic accidents (Treat et al 1977). Laboratory research suggests that drivers with low mental capacity are more likely to have accidents.

A driver characteristic influencing the ability to pay attention to the driving task while extracting traffic sign information from complex visual scenes is the perceptual style referred to as "field dependence." People who are field dependent have difficulty selecting relevant from irrelevant visual information and appear to be more readily distracted than those who are field-independent. The literature on this matter is divided on the relationship between field dependence and traffic accidents. There does appear, however, to be evidence that field-dependent drivers are poorer at detecting signs embedded in visual scenes (Loo 1978).

For a number of years there has been a concern about the potential for driver distraction and overload because of excess signage or signage unrelated to the driving task. It is known that drivers can only take in and process a certain amount of information without sacrificing other elements of the task required for safe and efficient driving. For this reason there are standards in the MUTCD dictating the maximum number of destinations, motorist services, etc. on a sign panel, and regulations about the proximity of advertising signs near rural freeways.

The effects of overloading drivers with too much sign information at one location may seem obvious, but the extent of the effect was not well understood until Gordon (1981) examined it in a series of experiments.

Subjects were required, in a laboratory experiment, to select the appropriate lane to be in to get to a specified destination when presented with a number of overhead freeway guide signs. Gordon showed that the presence of non-guidance information (e.g., bus lane, exit only) did not increase reaction time to obtain relevant destination information.

Gordon varied the number of guide signs (3, 5, and 8) presented and found that mean response times increased about 35% for place name destinations and 57% for route numbers as number of messages increased from 3 to 8. However, even the worst subjects (95th percentile reaction times) got the information in less than 5 seconds. A more realistic test of sign information processing involved the necessity for subjects to study a map containing information about their position and then, after being told their destination, to indicate the appropriate lane to be in, as in the previous experiments. This is more typical of the way drivers actually navigate, as they had to determine what information on the signs was relevant to their needs. Reaction times were somewhat longer under conditions where subjects had to read and understand the sign content rather than simply scan the content of the signs. Large numbers of errors were also found for some of the destinations. It is evident that overload involves more than simply the number of signs to be processed, but depends on what the driver must do with the information displayed. This study clearly illustrates the need to avoid driver overload and points out the need for drivers to make intelligent trip plans.

In addition to the issue of driver information load due to excessive traffic sign information, there is the possibility of distraction by advertising signs near roadways. There appears to have been relatively little research on this topic. However, it was examined in a series of five experiments by Johnston and Cole (1976), who used a variety of billboard advertising messages (nearly all with pictures and words) in an effort to distract driver attention in laboratory experiments that simulated some of the demands of the driving task. The distractors were color photos, several containing nudes. Small but statistically significant effects due to distraction were found for the measures of tracking and detection response time. The authors state that the driver has the capacity to shed irrelevant information and that "the general effect of distraction is not of great magnitude." They concluded that novel, sensuous, or moving displays are more likely to distract attention; that distractions should be minimal where the driver's load is high; and that glare from advertising signs should be controlled.

More recently, Andreasson (1985) summarized the literature on traffic accidents and advertising signs. In the three valid studies he found on advertising signs and accidents, either no relationships were found or any relationships that were claimed could not be attributed to these signs. No before-and-after studies have been done to provide conclusive data on this issue. The author concludes that "there is no current evidence to say that advertising signs, in general, are causing traffic accidents" (p. 105).

SIGNS

One of the most widely used and efficient ways of communicating information to drivers is with the use of traffic signs. This type of TCD has received more attention than have the others. For detailed review of the literature, see Dewar (1989). The work on this has included letter fonts and size, color combinations, retroreflectivity, amount of information, conspicuity, understandability of symbols, etc. One of the topics receiving considerable attention has been symbols. There are a number of advantages of symbols over word messages. They can be classified (e.g., as regulatory or warning) and identified at a greater distance and more rapidly and can be identified more accurately when seen at a glance (Ells and Dewar 1974); they are seen better under adverse viewing conditions (Ells and Dewar 1979); they can be understood by people who do not read the language of the country in which they are used. One of the main difficulties is that their meanings are not always obvious to the user. Although many are relatively easy to understand (e.g., NO LEFT TURN, CURVE), others present problems even for experienced drivers. Research by Hulbert and his colleagues (1979) and Pietrucha et al. (1985) has revealed relatively poor understanding of many symbols, in part because they are introduced into the system without drivers being properly educated about their meanings. Much of the work has also involved inadequate measures of comprehension.

One of the more extensive studies on TCD understanding was done by the American Automobile Association (AAA) by Hulbert et al. (1979). They examined comprehension of several traffic sign symbols, traffic signals and pavement markings with a large sample (over 3100) of drivers from across the United States. In a follow-up study conducted for the AAA a year later, Hulbert and Fowler (1980) used the same procedure but tested a different set of traffic control devices, including five traffic sign symbols. Comprehension levels were generally poor, with the percentage of correct responses to signs, signals, and pavement markings being 74, 68, and 45 in the first study. The corresponding figures for the second study were 59, 66, and 62 percent correct. Older drivers had more problems than did others.

A study of drivers' understanding of traffic sign symbols was undertaken for the FHWA by Knoblauch and Pietrucha (1986), who examined potential deficiencies in approximately 30 U.S. symbols and made recommendations for their improvement. Certain "families" of signs were found to be quite confusing (e.g., curves vs. turns; pedestrian vs. school signs). Many symbols were poorly understood.

Assuming that an adequate measure of comprehension has been obtained, there is still the issue of just what proportion of road users must understand a symbol in order for it to be safely used. Criterion levels of 65% have been used in some countries, but there is generally no clear statement of what is an acceptable level of understanding.

In many situations the information that would be most useful to the driver changes from moment to moment. To accommodate this need, engineers have developed "real time motorist information displays." These involve changeable message signs (CMS) to manage traffic under the following conditions: recurring problems (e.g., congestion); nonrecurring problems (e.g., accidents, construction); environmental problems (e.g., fog, ice); special operational problems (e.g., tunnels, drawbridges, contraflow lanes). As these systems developed, a number of ergonomics questions arose. What type of information do drivers need? Where should the information be located? What are the best ways to present the information? A large research effort in the United States addressed these issues and produced a "design guide" for real-time motorist information displays (see Dudek et al. 1978 for a review and Dudek 1990 for application guidelines).

SIGNALS

Traffic signals have more impact on travel behavior than any other TCD. Computers have enabled the use of signals which are very flexible - fixed or pretimed, traffic actuated, etc. However, they can be poorly designed, improperly placed and operated, and not properly maintained. They do not always increase safety and reduce delays.

One feature that gives drivers difficulty is the use of left-turn phasing. The three main types are:

- unprotected left turns (no exclusive phasing for left turns)
- protected-only left turns (a separate interval for left turns; they are prohibited at other times)
- protected/permissive left turns (protected phase during one interval - left turn arrow - and allows unprotected left turns on circular green).

Another factor is lead/lag phasing where protected left turns are either at beginning (lead) of the green phase or at the end (lag).

Difficulties with the understanding of traffic sign symbols has been fairly well documented, but relatively little research has addressed the understanding of traffic signals. With the great variety of signal phasing systems (including the various sign messages that accompany the signals) in operation in urban areas, the driver can easily become confused. For example, there is a surprising lack of understanding of left-turn signals. Hummer et al. (1990) examined driver understanding and preferences for a variety of left turn signals and different accompanying sign messages among 402 drivers in Indiana. Subjects were asked to choose one of four possible actions in response to the displays. Responses were scored as correct, close (conservative error), or gross error (actions with probable catastrophic consequences). Pairs of signal alternatives were also shown in order to determine preferences. Only 10.7% of the participants got all 9 comprehension questions correct, while 23% had more than half wrong (close or gross error).

The protected/permissive (p/p) displays gave drivers particular difficulties, with 23% making gross errors when the green ball only was displayed, and 14% when the green ball for through and green arrow for left turns were displayed. The presence of a sign with the signal display reduced gross errors in two of the three signal display configurations, suggesting that appropriate signing may reduce some of the difficulties in understanding signals. The authors conclude that protected signals are best understood and that p/p signals are least understood. The data indicate that most of the variables examined were unrelated to preference, but younger drivers did prefer a p/p signal, while those who drive less and those from rural areas preferred a lagging to a leading protected sequence for left turns.

Statistics indicate that a large proportion of accidents occur at signalized intersections. The effectiveness of installing signals at intersections has not been clearly demonstrated. However, research has shown rear-end collisions to be more common at these intersections. Mahalel and Prashker (1987) have analyzed the decisions faced by drivers approaching traffic signals as they turn from green to yellow. There is a zone during which the driver must decide whether to stop or continue through the intersection. This "indecision zone" has been defined as that range of distances from the vehicle to the intersection stop line which constitute the 10th to 90th percentiles of stopping probabilities. If the distance from the intersection is great enough essentially all drivers will stop, and if short enough none will stop. The area where a choice must be made has been broken down into the "dilemma zone," in which one can neither stop safely before the stop line nor cross the line before the red light, and the "option zone," in which the light turns yellow and one can either stop or cross the line before the red light. If a lead driver decides to stop, and the one following him/her decides to proceed through, there is a good probability of a rear-end collision. The point where the probability of stopping is .5 has the most potential for rear-end collisions. The use of a flashing green light to indicate that the end of the green phase is near has been found to increase rear-end collisions, as this increases the option zone. Further understanding of driver decision making and behavior at signalized intersections could enhance traffic safety.

Persaud (1988) has reviewed the literature on traffic signals and reports that, of the 14 before-and-after studies examined, 6 showed an increase in total accidents after signal installation, while 8 showed a decrease. He concludes that most research has shortcomings. The two common pitfalls he illustrates are regression to the mean and incorrect inferences from cross-section studies.

PAVEMENT MARKINGS

Paint markings on the road surface are an important source of information for drivers. They include all lines, words, and symbols on the pavement. Their function is to guide traffic into the correct position on the roadway and often to supplement signs and signals.

Words and symbols on the pavement must be elongated in order to present the appropriate visual image to the driver's eye. The order of the text is such that the message will read up with the first word nearest the driver. On the basis of studies by Gordon (1976) as well as by Hulbert et al. (1977) and Hulbert and Fowler (1980), it appears that markings are not well understood.

NAVIGATION

A good deal of work has been done on TCDs as they relate to the guidance task. However, the navigation component of the task has been somewhat neglected by human factors researchers. King and Mast (1987) have summarized the work on excess travel, defined as the difference between total actual highway use excluding destination-free "pleasure" driving and the travel required had the optimal route been used. They determined that excess travel is due to suboptimal navigation strategies, route selection, and route planning and to problems in the highway information system. This is a concern for reasons of both safety and economy. After synthesizing the available data from various parts of the world, the authors conclude that excess travel constitutes 4% of all vehicle miles travelled and 7% of all travel time for work-related trips. The corresponding figures for non-work-related trips are 20 and 40%, respectively. They estimate the total annual cost in the U. S. to be more than $45 billion.

Evidence of the problems which drivers have with navigation are illustrated by two studies by King (1987a; 1987b). In one study (King 1987a) subjects were required to drive a 50- or a 15-mile route, going to a number of specific destinations along the way, under three conditions of navigational information. Significant excess travel was found.

In another study, King (1987b) surveyed 125 drivers about their navigational and trip planning abilities. They also rated the effectiveness of various remedial measures that would help navigation on the road. The three most highly rated measures all involved improving directional and information signing. The provision of automatic in-vehicle navigation systems that show the vehicle location or the best route was rated very low. This has interesting implications for the acceptance and use of high-technology systems intended for navigation.

One of the most important developments in traffic control and navigation in the past decade is the rapid growth of Intelligent Vehicle/Highway Systems (IVHS), which can provide the driver with detailed information about his/her location in the street or highway network, as well as when to make a turn, optimal routes to follow in the event of accidents or congestion, distance and time to destination, and information about vehicle status. In future the driver may well get less traffic control information from TCDs and more from inside the vehicle. However, a good deal of research is needed on driver acceptance and the safety implications of such high technology in vehicles (Wierwille et al. 1988)

It is evident from the work on driver navigation ability that an effort should be made to develop and apply the very successful system called "positive guidance." This is particularly the case in view of the increasing numbers of older drivers, who are more readily confused and distracted in busy traffic environments.

ACCIDENTS AND TCDs

The relationship between accidents and traffic control devices has been an elusive topic, except possibly in the case of signals installed at intersections. Police reports may indicate that the "cause" of a collision was failure to obey a sign or signal, but this may be only one among a number of contributing factors.

The safety effects of signals have been examined more than have those of other TCDs. For example, Datta and Dutta (1990) reviewed the literature on installation of signals at intersections and report that most studies find a decrease in right-angle accidents, but an increase in rear-end and left-turn accidents. In their own work Datta and Dutta studied 102 intersections before and after signals were installed. They found patterns similar to those found by others. Rear-end collisions were 53% higher and head-on, left-turn accidents, 50% higher, while right-angle accidents 57% lower after installation. These findings raise the question of driver behavior during the approach to signalized intersections as the light changes.

OTHER TYPES OF TCDs

The TCDs discussed above are the most widely used; however, there are others used for specialized purposes. Object markers indicate obstacles that are in or near the roadway. Delineators (reflectors on posts or on the pavement) are used for vehicle guidance, especially around curves at night. Flashing beacons are used to warn motorists of especially hazardous situations where a sign is not enough. Raised pavement markers, small discs, or humps a few inches in diameter on the road surface are used to improve visibility at night and in wet weather. Traffic cones and barricades are used to route traffic and warn drivers in work zones. Rumble strips are used to alert drivers about a changed condition (e.g., reduced speed, end of a freeway). Unfortunately, relatively little human factors research has been done on these TCDs.

TRAFFIC CONTROL IN CONSTRUCTION ZONES

One location which appears to present a challenge for safe traffic control is the construction zone. This problem has received a good deal of attention over the past two decades (e.g., a special issue on the topic in the ITE Journal, April, 1979); nevertheless, there continues to be concern for the safety of drivers and workers in construction and maintenance zones.

The need to warn drivers well in advance of hazards under such conditions is obvious. It has been suggested that drivers may require 10.2 to 11.7 sec. to detect, recognize, make a decision, and execute a proper maneuver for a lane change in a construction zone (Warren and Robertson, 1979). On the basis of a review of relevant research, it has been suggested that "approximately 2/3 of work zone safety problems could be ameliorated if current standards and knowledge were properly applied" (p. 32). It appears that a major source of the problem is proper implementation of existing regulations and TCDs, rather than design of the TCDs themselves.

Odgen et al. (1990) examined understanding of traffic signs in urban work zones by interviewing 205 drivers. They were asked about signing and viewed specific signs presented in a pamphlet of photographs. The word message CONSTRUCTION 500 FEET was correctly identified by only 2/3 of the subjects - 25% thought it meant construction would continue for 500 feet. The low shoulder symbol was very poorly understood - 84% thought it meant uneven pavement. The work message NO CENTER LANE was understood by fewer than half the subjects. The appropriate maneuver for the CROSSOVER word message with an arrow (seen in context with the sign mounted on a delineation barrel) was at a low level, with 55% saying they could turn before the barrel, while 38% thought turns were not permitted before the barrel. This is an example of where drivers may know what a sign means, but not where to make the appropriate maneuver.

COMPLIANCE WITH TCDs

An important consideration in determining whether a TCD is effective is whether drivers act upon the information they convey. In the case of regulatory messages this is the issue of compliance. It is quite likely that many accidents which involve failure to comply with TCDs are not identified as such.

A "violation" could occur for a number of reasons:

- the driver deliberately violates the TCD,
- the TCD is difficult to detect due to poor placement or visual overload in the roadway environment,
- the device is not legible or understandable because of poor design features or poor maintenance, or
- the violation is of a traffic law rather than a TCD.

Pietrucha et al. (1989) measured the actual compliance with specific TCDs at 906 selected locations. Of the 79,055 drivers observed at traffic lights, 3.5% entered on a yellow signal and about 1% entered on the red. Of the more than 31,000 drivers observed when turning right at a red signal, 61.3% did not stop properly, but only 1.4% were involved in conflicts as a result of this. Approximately 2/3 of the drivers observed failed to come to a full stop at STOP signs, and 1.3% of these cases resulted in a traffic conflict. Illegal left turns were made at NO LEFT TURN signs by 1.6% of the 53,165 drivers observed.

METHODOLOGY

A great variety of methods have been employed for the evaluation of traffic signs (see Dewar and Ells 1984 for a review). Methods can be divided into field (on-the-road) and laboratory procedures. Engineering evaluations often come in the form of complaints from drivers or a series of accidents at an intersection. Assessment based on "expert" opinion is also a common approach to both the evaluation of existing signs and the development of new ones.

The ultimate index of the adequacy of a traffic sign is how quickly and clearly the message is understood by drivers on the road. However, it is too costly to conduct field evaluations of all signs. A more efficient and much less expensive approach is to evaluate them in the laboratory. Psychological and psychophysical measurements such as reaction time, glance legibility, legibility distance, comprehension, preference ratings, and signal detection have been successfully employed to gauge the effectiveness of both existing and new signs. Laboratory techniques have the advantage of economy of time and money. However, it is essential to ensure that these methods are properly validated against on-the-road measures. Unfortunately, there has been a tendency to accept these methods without properly validating them against measures taken in the driving environment.

One of the few studies to use and combine a number of measures was that of Roberts et al. (1977), who compared the symbolic and text versions of 19 traffic sign messages. Most messages had one text and four symbolic versions. Five measures were used: understanding time (the time required to indicate a sign's meaning), comprehension, certainty (how confident the subject was of his/her understanding of the sign's meaning), preference (rank ordering of the symbols used to convey a specific message), and identification time (minimum exposure time at which subjects could accurately identify all elements of the symbol). The authors derived an "efficiency index" for each symbolic version of each message - what they called the "relative 'goodness' of performance" of that symbol.

A method that has shown success in designing more effective symbolic signs is the low-pass optical technique of Kline et al. (1990), who were able to increase the legibility distances of symbolic highway signs for young, middle-aged, and elderly drivers. To identify and thus avoid the problems of contour legibility and interaction between adjacent contours in regulation symbolic highway signs, the experimenters viewed versions of them blurred by strong positive sphere lenses. The visibility distances and comprehension of standard text, standard symbolic and the "improved" symbolic highway signs which resulted were then compared among young, middle-aged, and elderly observers. The average distance at which standard symbolic signs could be identified was about two times that of standard text signs. The visibility distances of their improved symbolic signs, however, were about three times those of standard text signs and 50% greater than those of standard symbolic signs, demonstrating that their optical approach can be used to enhance the visibility of symbolic highway signs for drivers of any age.

ISSUES FOR FURTHER RESEARCH

- Scientific methods for TCD design and use.
- Human factors basis for current design and use.
- Perception and comprehension of traffic signals and pavement markings by elderly road users.
- Effectiveness of TCDs in work zones.
- Education of drivers about new TCD's.
- Development of a "positive navigation" philosophy and methods to complement the "positive guidance" approach.
- Implementation of current standards.
- Relation of TCD adequacy to traffic safety.

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Highway Design, Highway Safety, and Human Factors

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INTRODUCTION

The goals of the highway design engineer include providing roadway facilities which can be safely negotiated by various road users, even under less-than-ideal weather and environmental conditions. To help accomplish this goal, a basic understanding of human characteristics and behaviors as they relate to roadway design features is needed. Road users of interest include not only passenger car drivers, but also drivers of trucks, motorcycles, bicycles, and other vehicles, as well as pedestrians.

The purpose of this paper is to discuss some of the basic safety concepts which are currently known regarding roadway geometric features. Also, gaps in human factors knowledge are identified for which additional research is needed. Roadway features covered include cross-sectional elements (including roadside features), horizontal and vertical alignment, pedestrian and bicycle facilities (including transition curves), intersections, and interchanges. Traffic control devices such as signs, signals, and markings are not covered in this paper.

In discussing each of these topics, it is important not only to concentrate on the "average" driver, but also to point out situations where data exists for certain vehicle types (e.g., heavy trucks) or certain driver populations (e.g., older drivers) which indicate a heightened risk of crash. A major problem here is in defining this heightened risk, due largely to the lack of good exposure data for specific vehicle or driver subgroups. For example, we do not know whether elderly drivers have more problems on horizontal curves than other drivers because of the lack of exposure information on drivers by age in the exposed population. Also, very little exposure data are available on large trucks (by truck size) or pedestrian and bicycle volumes for use in determining the types of roadway features and facilities which affect their safety. Given these problems, the following discussion will explore what is known and what human factors questions remain unanswered.

CROSS-SECTIONAL DESIGN ELEMENTS

Cross-sectional roadway elements are features which are part of a cut-away view of the roadway and include the number of lanes, lane width, shoulder width and type, median width, and roadside design (e.g., roadside slope, placement of roadside obstacles). Elements of a rural two-lane cross-section are shown in Figure 1. From a human factors standpoint, cross-sectional elements can serve several purposes, such as helping drivers to stay in their proper lane (e.g., wide lanes, turn lanes), allowing drivers a place of escape or refuge in an emergency (e.g., wide shoulders and medians), and helping a driver to safely return to his/her lane after leaving it (e.g., mild roadside slopes, paved shoulders).

Not all accident types appear to be affected by cross-sectional elements. From a 1987 study by Zegeer et al. of accident relationships on two-lane roads in seven states, accident types related to lane and shoulder width, shoulder type, and roadside condition include run-off-the-road (fixed object, rollover, and other run-off-the-road), head-on, and opposite and same-direction sideswipe accidents, termed together as "related" accidents. Accident types such as rear-end and angle were not affected by such features. The following is a discussion of several specific cross-sectional elements.

Lanes and Shoulders

The safety literature generally shows that wider lanes and shoulders are associated with reduced accident rates. For example, as illustrated in Figure 2, the number of related accidents (per mile per year) decreases for increases in lane width, or paved shoulder width, based on the seven-state study. A small but significant accident reduction was found from having paved shoulders compared with unpaved shoulders. This study included mostly higher-class two-lane roadways, with traffic volumes generally higher than 1,000 vehicles per day.

While many other studies also support the general trend of reduced accidents for increased lane and shoulder width, one recent study has found evidence that on lower-class, low-volume roads, accident rates may be higher on roadways with 10-foot-lanes (with no shoulder) than on 8- and 9-foot lanes. One possible explanation is that drivers could be slowing down on these very narrow roads (and thus having fewer accidents) and traveling faster on the 10-foot lanes, even though the severe alignment (and hazardous roadside design) on the 10-foot-lane roads is often not adequate to safely handle these higher speeds. Thus, one research issue of interest is:

> What is the nature of driver behavior on various roadway widths, in terms of speeds and lateral placement in their lanes, and how is this behavior affected by roadway alignment?

Concern has also grown in recent years regarding driving behaviors of older drivers. In addition, the accident experience of teenage drivers has long been recognized as a safety problem. One of the issues of concern involves how these two populations of drivers handle their vehicles on roadways with restricted lane and shoulder widths. Therefore, another research issue is:

> Once out of lane, how do different driver groups (e.g., teenagers, elderly) recover? Is there an envelope of recovery angles at different speeds for different driver groups?

Roadside Features

The condition of the roadside is another cross-sectional element which affects crash severity and frequency. This is due to the high percentage of crashes, particularly on two-lane rural roads, which involve a run-off-the-road vehicle. Providing a more forgiving roadside relatively free of steep slopes and rigid objects will allow many of these off-road vehicles to recover without having a serious crash.

In terms of the probability of a crash involving the roadside, studies have shown that greater roadside "clear zones" will greatly reduce crash occurrence. For example, the proportion of related accidents on two-lane roads has been found to be reduced by 13 to 44 percent for increases in roadside recovery distances of 5 to 20 feet, respectively. Flatter roadside slopes were also found to have a substantial effect on single-vehicle accidents. As illustrated in Figure 3, accident rates drop steadily as sideslopes are flattened from 3:1 (i.e. a slope corresponding to a drop of 1 foot for every lateral distance of 3 feet) to 7:1 or flatter. However, very little accident reduction (only 2 percent) is expected from flattening a 2:1 slope to 3:1. The probability of vehicle rollovers is substantially reduced for sideslopes flatter than 4:1.

In addition to crash frequency, the design of roadside features also can affect accident severity. The types of roadside objects which are related to higher crash severities include large trees, wooden utility poles, bridge ends, concrete culverts, rocks and rock walls, and spear-end guardrail terminals, among others. Those objects typically resulting in reduced accident severity when struck by a motor vehicle include sign posts, fences, small trees and brush, and breakaway devices (e.g., crash attenuators, breakaway sign and luminaire poles).

While past research has clearly found roadside conditions to be of major importance in crash experience, most of the needed research involves how to better quantify the accident severity associated with specific types of roadside hardware (e.g., guardrail sections and ends, bridge rails, breakaway luminaire and utility poles, crash cushions and barriers) for various vehicle types, speeds, and impact angles. Also, there is a need to conduct further research to develop and test improved barrier systems which can then be installed in the field to reduce crash severity for all vehicle classes ranging from small cars, vans, and utility vehicles to large trucks.

We know that accident severity can also be greatly affected by the type of vehicle, use of occupant restraints, vehicle speed, and many other factors. Thus, while the highway safety community can urge drivers to wear safety belts, drive within the speed limit, not to drink and drive, buy "safer" cars, slow down on wet roads, and other such actions, it is probably not fruitful to try to train drivers to dodge certain obstacles once they have left the roadway. This is because most fixed-object and rollover accidents occur after a driver has essentially lost control of his vehicle and probably could not steer his way out of the accident. For example, a driver whose vehicle begins to tumble down a steep slope after missing a sharp horizontal curve may have little control over which tree is struck or even whether the vehicle rolls over. Thus, human factors issues of interest do not involve the actual design of the roadside hardware. On the other hand, there are numerous roadway and geometric improvements which can help to reduce the likelihood that the driver will off the road.

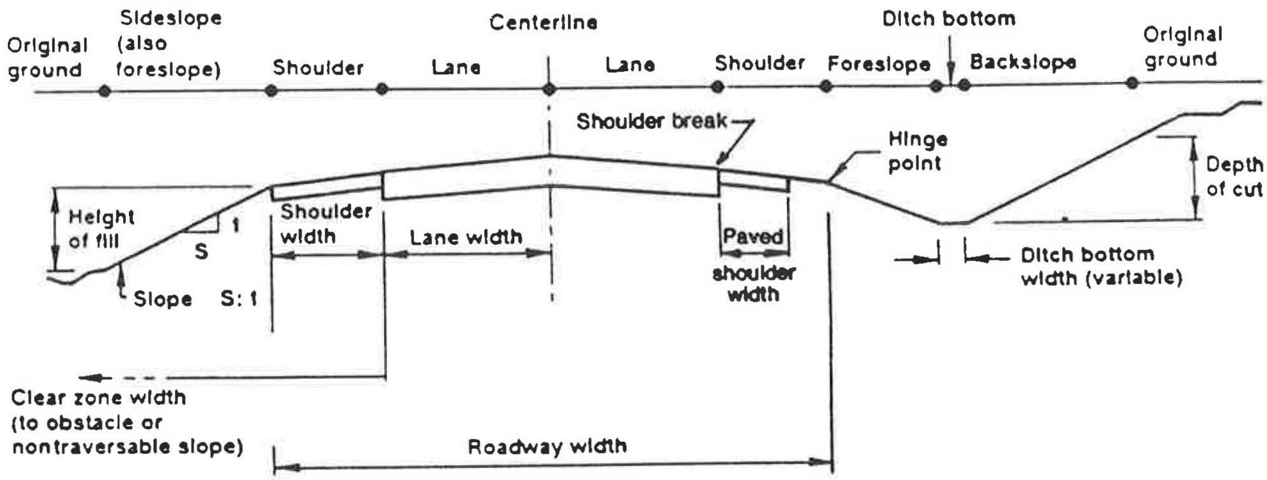

Figure 1. Elements of rural highway cross sections.

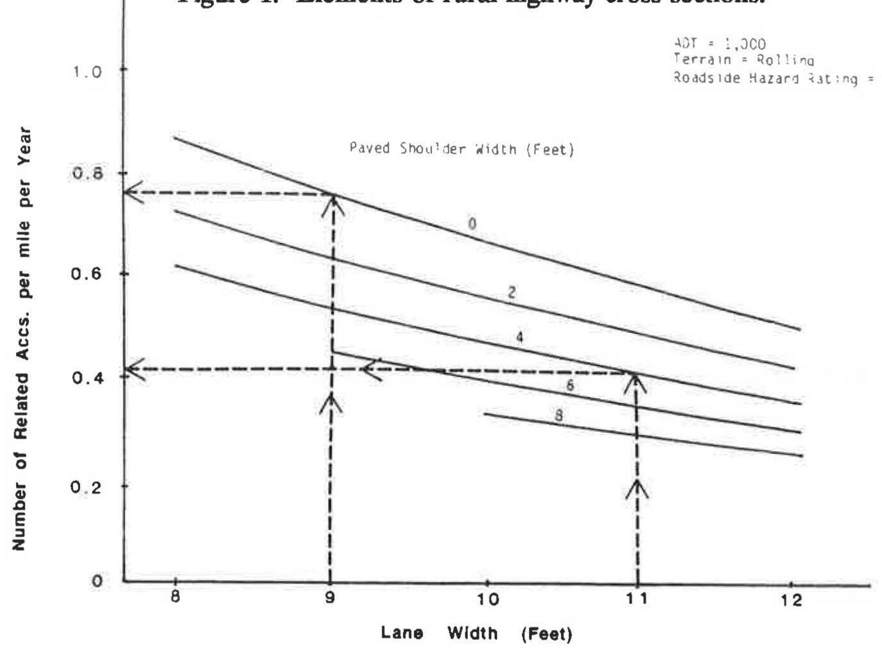

Figure 2. Relationship between accidents and lane and shoulder width.

Therefore, in terms of human factors research needs related to roadside safety, the primary issues of concern include:

1. What causes drivers to leave the roadway in the first place, and what are the probabilities of various roadside encroachment distances for various classes of drivers and vehicles?
2. Further, what types of improvements would be most effective in reducing the probability that a driver will off the road?

Highway Bridges

Highway bridges are sometimes associated with accident problems, particularly rural highway bridges with narrow width, poor sight distance (e.g., a bridge just past a sharp horizontal curve), and/or with inadequate signing and delineation. Numerous studies have analyzed the effects of various traffic control devices (e.g., signs and markings) on crashes and on vehicle operations (e.g., speed change and vehicle placement on the bridge). However, research is scarce on the effects of bridge geometrics on crash experience. The features which are most important in terms of affecting bridge accident rate are bridge width and the width of the bridge in relation to the approach width. The best-known accident relationship with bridge width was developed in a 1984 study by Turner, where an accident model was developed as a function of "relative bridge width" (RW), which is defined as the bridge width (C) minus the width of the traveled way (B) (see Figure 4).

According to Turner's model, and as shown in Figure 5, the number of accidents per million vehicles decreases as the relative bridge width increases. This relationship indicates that it is desirable to have bridge widths at least 6 feet wider than the traveled way. In other words, shoulders of 3 feet or more should be provided on each side of the bridge. Thus, the key human factors questions regarding bridges include:

1. How do drivers react (if at all) to various narrow bridge situations in terms of when they perceive a potential danger?
2. At what point do drivers adjust their speed when approaching a narrow bridge, and what type of traffic control or delineation increases their awareness of the bridge at night?

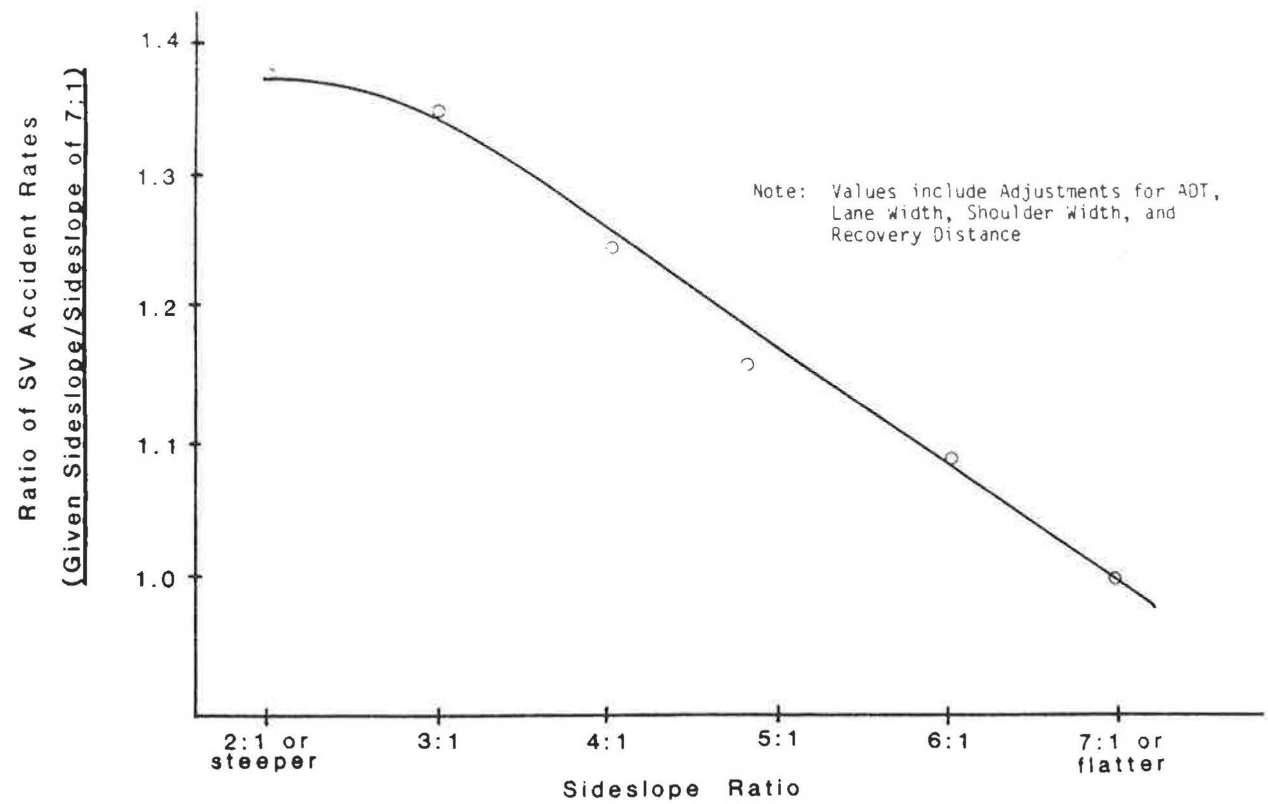

Figure 3. Relationship between accidents and sideslope.

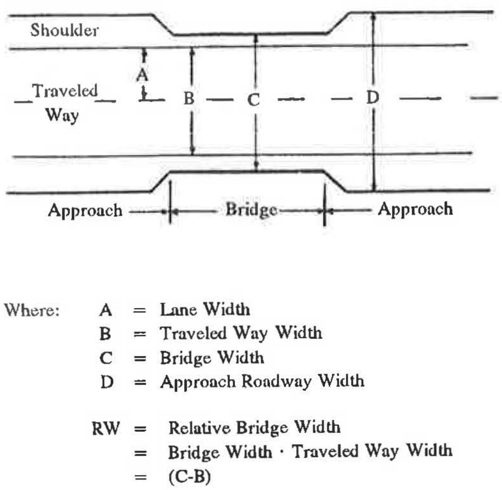

Figure 4. Key elements of a bridge site.

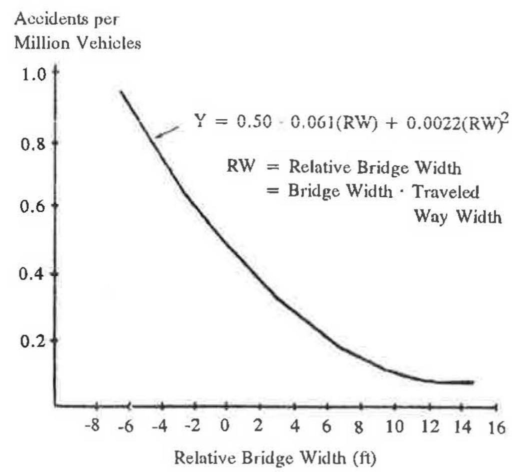

Figure 5. Accident rate by relative bridge width.

Median Design

Elements of median design which may influence accident frequency or severity include median width, median slope, median type (raised or depressed), and presence or absence of a median barrier. Wide medians are considered desirable in that they reduce the likelihood of head-on crashes between vehicles in opposite directions and may reduce other "same direction" crashes by providing an emergency "escape" area. Median slope and design can affect rollover accidents and also other single-vehicle crashes. The installation of median barriers typically increases overall accident frequency due to the increased number of impacts to the barrier, but reduces crash severity by redirecting or eliminating head-on impacts with opposing traffic. A controlling factor in median width is often the limited amount of highway right-of-way which is available.

The two major studies conducted to date on safety effects of median design include those by Foody and Culp (1974) and Garner and Dean (1973). Taken together, the two studies indicate that where a wide median width can be provided (e.g., 84 feet or greater), a mildly depressed median (depressed by 4 feet with 8:1 downslopes) and mound median (3:1 upslope) provide about the same crash experience. However, in cases with narrower medians (e.g., 20 to 40 feet), slopes of 6:1 or flatter are particularly important. Deeply depressed medians with slopes of 4:1 or steeper are clearly associated with a greater occurrence of overturn crashes. While accident relationships are unclear for median widths of less than 20 feet, wider medians in general are better, and median widths in the range of 60 to 80 feet or more with flat slopes appear to be desirable, where feasible.

With these points in mind, some of the key human factors questions of interest related to median design are:

1. How is a driver's perception of the true hazard affected by median width, type, and design?
2. Do medians of certain widths result in underjudgment of true risk?
3. How does the presence of concrete median barriers affect the speed and placement of vehicles in the adjacent lanes?

Multilane Design Alternatives

Although most two-lane roads carry relatively low traffic volumes, considerable safety and operational problems exist on some higher-volume roads, particularly in suburban and commercial areas. Various types of geometric treatments have been used to reduce such problems, such as passing lanes, short four-lane sections, turnout lanes, and two-way left-turn lanes (TWLTLs). A 1985 study by Harwood found that TWLTLs can reduce accidents by approximately 35 percent in suburban areas and as much as 75 to 85 percent in some rural areas. Accident reductions of 25 to 40 percent were reported for passing lanes, short four-lane sections, and turnout lanes.

A 1986 NCHRP study by Harwood investigated multilane designs for suburban areas. These designs generally involve adding one or more lanes to a two-lane road design and are generally more extensive than the two-lane undivided road alternatives discussed above. These include designs with between 3 and 7 lanes, where some are divided and some are not, as shown in Figure 6. Based on an accident analysis, the 3-lane design with TWLTL had a safety advantage over the 2-lane undivided design and requires only a minor amount of increase in road width. Four-lane undivided highways had generally higher accident rates than other multilane designs, partly because of the lack of special provisions for left-turn vehicles. Installation of a five-lane highway with a TWLTL was associated with reduced accident rates compared with other four-lane design options.

Several human factors issues should be addressed to help gain a better understanding of multilane design alternatives:

1. How do drivers react to turn lanes?
2. Why do some drivers make their turns from a through lane rather than use a TWLTL or other turn lane?

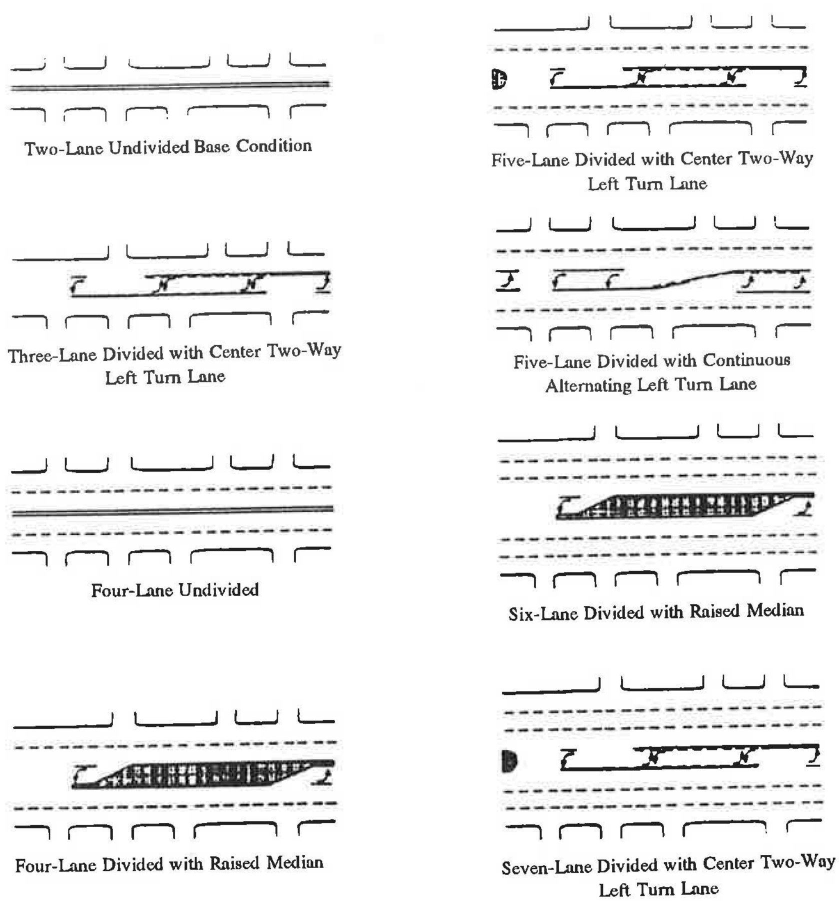

Figure 6. Multilane design alternatives.

HORIZONTAL ALIGNMENT

Accident studies indicate that horizontal curves experience a higher accident rate than tangents, with rates ranging from one and a half to four times greater than those for tangent sections. Past research studies have identified a number of traffic, roadway, and geometric features which are related to safety of horizontal curves. Those factors related to higher accident frequency on horizontal curves include higher traffic volumes, sharper curvature, greater central angle, lack of a transition curve, narrower roadway, more hazardous roadside conditions, less stopping sight distance, steep grade on curve, long distance since last curve (which can create a driver expectancy problem), lower pavement friction, and lack of proper signs and delineation.

A 1991 study by Zegeer et al. for FHWA found that the types of accidents generally found to exhibit higher percentages on horizontal curves compared with tangents included more severe (fatal and A-type injury) crashes, head-on and opposite -direction-sideswipe crashes, fixed-object and rollover crashes, crashes at night, and crashes involving drinking drivers.

A 1983 study by Glennon et al. investigated many safety and operational effects of horizontal curve features. They found that greater speed reductions for approaching vehicles were found to be associated with sharper horizontal curves. The authors also found that there was a measurable benefit of spiral transition curves, since they drastically reduce the friction demands for vehicles. The study also found that such elements as curve length and sharpness, shoulder width, roadside condition, and pavement skid resistance were important in the probability that a curve will be a high-accident site.

The accident effects of numerous curve features were quantified in the 1991 FHWA study by Zegeer et al., which involved a sample of 10,900 curve sites. Curve flattening can lead to reduced run-off-the-road crashes. For example, from Table 1, flattening a 20-degree curve to 5 degrees on a 40-degree central angle would result in an expected 64 percent reduction in curve crashes. Roadway widening on curves can reduce accidents by up to 21 percent for 4 feet of lane widening (e.g., widening from 8- to 12-foot lanes) and as much as 33 percent for shoulder widening (e.g., adding 10-foot paved shoulders). The presence of spiral transition curves can reduce accidents by approximately 5 percent, while correcting deficient superelevation was associated with a 10 to 12 percent accident reduction.

Based on these and other research findings, some of the primary human factors issues related to horizontal curves include:

1. At what point do drivers perceive a curve, and what are their cues?
2. How do drivers judge the sharpness of a curve before entering? Under what conditions are they underestimating or overestimating curve sharpness?
3. Once on a curve, how do drivers "track" in terms of visual cues? How do distractions (e.g., other vehicles) affect tracking?
4. Do different driver groups track differently (e.g., inexperienced, elderly)?
5. What advanced signing do drivers actually notice? How do drivers perceive and react to roadway delineation, chevron signs, etc., particularly at night?
6. Do drivers track better on spiralled horizontal curve entries and exits compared with curves with no spiral curves? Why or why not?

VERTICAL ALIGNMENT

The vertical alignment of a highway consists of the vertical curves (i.e., sags and crests) and the grades (upgrades and downgrades). While formal safety research on vertical alignment is limited, evidence shows that accident experience is higher on roadways with steeper grades and more severe vertical curves (particularly crests, where sight distance is restricted). Studies have also found large trucks to have particular accident problems on steep upgrades (particularly at night because of higher-speed passenger cars striking the rear end of slow-moving trucks) and long downgrades (where truck brakes fail, causing the trucks to run off the road or run into passenger cars). Certain combinations of vertical and horizontal alignment are believed by some designers and researchers to present particular problems to motorists, although the specifics of this problem have not been properly quantified.

Some of the research questions of concern relative to vertical alignment include:

1. How do truck drivers perceive downgrades? Does a downgrade affect a driver's perception of a horizontal curve?
2. How do drivers (and truck drivers in particular) react to various combinations of horizontal and vertical alignment?

Table 1. Percent accident reductions for curve flattening project.

Degree of Curve		Central Angle in Degrees									
		10		20		30		40		50	
Original (Do)	New (Dn)	Non-Isolated	Isolated*	Non-Isolated	Isolated	Non-Isolated	Isolated	Non-Isolated	Isolated	Non-Isolated	Isolated
30	25	16	17*	16	17	16	17	15	16	15	16
30	20	33	33	32	33	31	33	31	33	30	33
30	15	49	50	48	50	47	50	46	50	46	50
30	12	59	60	57	60	56	60	55	60	55	60
30	10	65	67	64	66	63	66	62	66	61	66
30	8	72	73	70	73	69	73	68	73	68	73
30	5	82	83	80	83	79	83	78	83	78	83
25	20	19	20	19	20	18	20	18	20	17	20
25	15	39	40	38	40	36	40	36	40	35	40
25	12	50	52	49	52	48	52	46	52	46	51
25	10	58	60	56	60	55	60	54	59	53	59
25	8	66	68	64	68	62	68	61	67	60	67
25	5	77	80	75	80	74	79	72	79	72	79
20	15	24	25	23	25	22	25	21	25	20	24
20	12	38	40	36	40	35	40	34	39	33	39
20	10	48	50	45	50	44	49	42	49	41	49
20	8	57	60	54	60	52	59	51	59	50	59
20	5	71	75	68	74	66	74	64	74	64	74
15	10	30	33	28	33	26	33	25	32	24	32
15	8	43	46	40	46	37	46	35	45	34	45
15	5	61	66	56	66	53	65	51	65	50	65
15	3	73	79	68	79	64	78	63	78	63	78
10	5	41	49	36	48	32	48	29	47	28	47
10	3	58	69	50	68	45	67	43	66	42	66
5	3	22	37	15	35	13	33	11	32	11	31

*Isolated curves include curves with tangents of 650 ft (.124 mi) or greater on each end.

3. How do drivers react to various crest vertical curves in terms of their speed profile for mild vs. severe curvature?
4. How much of the vehicle ahead do drivers need to perceive and DO THEY NEED TO judge its speed profile for mild vs. severe vertical alignment?

PEDESTRIAN AND BICYCLE FACILITIES

Collisions between pedestrians and motor vehicles continue to represent a serious safety problem in the United States. In 1989, for example, 6,552 pedestrians were killed, and an estimated 112,000 pedestrians were injured during that same year. In addition, approximately 900 bicyclists are killed and thousands injured in collisions with motor vehicles. While dozens of different types of traffic control measures have been used in an effort to reduce accident risks for pedestrians and bicyclists, little quantitative information is available on the accident effects of specific geometric improvements.

Perhaps the most beneficial facilities for pedestrians are well-designed sidewalks and pedestrian pathways. Research by Knoblauch et al. (1987) has shown a clear safety benefit from such facilities, based on pedestrian accident and exposure data. Based on research in Japan, grade-separated crossings (i.e., overpasses and underpasses) have also been found to reduce accidents involving pedestrians who need to cross major streets. However, the installation of such facilities is quite expensive, and their effectiveness depends largely on their use by pedestrians. Many pedestrians are unwilling to use overpasses or underpasses, because of their inconvenience, the walking distances involved, and the time to cross compared with crossing at street level.

Other geometric facilities which are believed to be beneficial to pedestrians under certain conditions include refuge islands (on wide streets), pedestrian malls, widened lanes and shoulders (particularly in rural areas), and various neighborhood traffic control measures (e.g., traffic circles, cul-de-sacs). Many other types of nongeometric measures (e.g., barriers, overhead lighting, signs, crosswalks, pedestrian signals) have also been used with varying degrees of success.

While various types of signs, signals, and other roadway improvements are sometimes used in an attempt to improve bicycle safety, bicycle lanes and bicycle paths are the roadway measures probably most beneficial in reducing collisions between bicycles and motor vehicles. This is because these two measures allow for separation of bicycles from motor vehicle travel.

Human factors issues may be discussed in terms of the pedestrians and bicyclists themselves, or in terms of how motor vehicle drivers are influenced by these types of highway users. Issues related to pedestrians (which may vary widely by region of the country, ethnic group, sex, etc.) include:

1. What are the walking speeds of various groups of pedestrians (e.g., age group, handicapped pedestrians, joggers)?
2. How well do pedestrians understand the meaning of proper use of pedestrian signals, pushbutton signals, signs, crosswalks, refuge islands, and other measures?
3. How do pedestrians behave when attempting to cross streets at intersections (by type of signal control), or at midblock locations (for narrow and wide streets, with and without medians, by age group, etc.)? For example, how observant are pedestrians of motor vehicle traffic? Do pedestrians practice proper search behavior? Do they cross during the appropriate interval? What is their gap acceptance when crossing roads and streets with no signal control?
4. How do pedestrians behave when walking along roadways at night and during the day in terms of where they walk (placement in the lane, on the shoulder, etc.), the types of routes that they select, the side of the street where they walk, etc.?

Examples of human factors issues for bicyclists (which can also be determined by bicyclist age, sex, region of the country, etc.) include:

1. How do bicyclists behave with respect to their speeds and where they ride their bikes (e.g., on the sidewalk, on the shoulder, placement in the travel lane, etc.)?
2. How do bicyclists behave with respect to compliance with stop signs, yield signs, traffic signals, and direction of travel on two-way and one-way streets and when making right and left turns?
3. What is the understanding by bicyclists of rules of the road and traffic control measures? Does understanding translate into practice? Are there ways to ensure both better understanding and practice?

With respect to motor vehicle drivers and how they are affected by pedestrians and bicyclists, issues include:

1. How do drivers position their vehicles and adjust their speeds when passing a pedestrian or bicyclist on a road with no shoulder (as a function of road width)?
2. How does driver behavior change for various widths of paved shoulder or in the presence of bike lanes?
3. How do drivers react to pedestrians who cross streets in front of them, in terms of their speed profile, recognition of the pedestrians, attitude about pedestrians? Also, what is the general driver understanding of laws and regulations concerning yielding to pedestrians in crosswalks and yielding to them when making right or left turns? Again, does understanding affect practice?
4. How soon do drivers detect pedestrians and bicyclists during daytime and nighttime conditions under various traffic and roadway conditions and for various levels of reflectivity on the pedestrian and bicyclist, headlight illumination, etc.?

INTERSECTION GEOMETRICS

While at-grade intersections cover only a relatively small part of the total roadway network, they represent a large part of the accident problem. Over one-half of the motor vehicle accidents in the nation occur at intersections. As the nation becomes more urbanized, intersection accidents will continue to be a growing part of the total accident problem. Based on research to date, it appears that the severity of crashes at intersections is decreasing slightly over time, perhaps because of the urbanization of society. Crashes at urban intersections are more likely to be at lower speeds than similar crashes at rural intersections, and thus driver injury would be expected to be less.

Based on unpublished data from two states within the Federal Highway Administration's "Highway Safety Information System," it appears that approximately 10 to 15 percent of urban intersection accidents are head-on, turning collisions, approximately 30 percent are right-angle collisions, and approximately 10 percent are rear-end impacts. The same patterns hold true for rural intersections, with the percentage being slightly lower in each of three major categories. Preliminary information has also indicated that when one looks at accidents involving different driver groups at signalized intersections, elderly drivers appear to have more problems than do middle-aged drivers with both left-turning accidents (in which the vehicle turns left in front of an oncoming vehicle) and right-angle collisions. At stop-controlled intersections, elderly drivers are more likely than middle aged drivers to be involved in accidents which involve starting from a stop and turning.

With respect to specific geometrics at intersections, it appears that both stop-controlled and signalized T-intersections (intersections in which one road dead-ends at a second road) have lower accident rates than four-way intersections (intersections in which two roads cross each other) in rural areas. Also, stop-controlled T-intersections have lower rates in urban areas where the intersection handles more than 20,000 vehicles per day. Clearly, part of the reason for this finding is that T-intersections eliminate certain maneuvers (e.g., opposing through and left-turning vehicles on the dead-end road). This reduces the probability of certain crash types such as accidents resulting from vehicles running the traffic signal or failing to yield during a left turn. In short, overall exposure to risk is decreased.

With respect to sight distance (the distance provided a driver approaching the intersection to see a vehicle in the same roadway or coming from a crossing road), poor sight distance was found to increase total accident rate by 15 to 20 percent in one study. It is noted in another study that "specific reductions in accident rate expected from specific increases in sight distance remains open to question." Thus, this issue is still being studied.

A second major design characteristic at intersections is the degree of "channelization" -- the degree to which traffic islands and raised markers or curbs are used to channel traffic into certain patterns. Channelization is often used to provide left-turn lanes by using part of the existing median. There is some indication in the research literature that multivehicle accident involvements do indeed decrease with channelization. In other studies, it appears that for rural intersections, "passing" accidents (i.e., accidents in which a vehicle overtakes and passes a vehicle travelling in the same direction) decrease with left-turn lanes. Passing accidents at intersections would normally involve vehicles attempting to make left turns.

In summary, there are various geometric characteristics that can be modified in the design of at-grade intersections. Unfortunately, we do not know much about the actual effects of left or right turn lanes, channelization, offset T-intersections to replace four-way intersections, minimum intersection spacing in urban areas, or other design changes. In addition, from the human factors perspective, we know little about why drivers are involved in certain types of angle and turning accidents, particularly given that many of these occur at intersections where sight distance is adequate and/or where signalization is present. Thus, from the human factors perspective, the following issues are of interest.

1. In general, intersections are roadway elements where accidents tend to cluster because of conflicting or merging vehicle maneuvers. How do different groups of driver (i.e., by age or experience) perceive possible risks at intersections -- what do they "see" under different levels of distraction (traffic)? More important (from a roadway design perspective), what risks do they not see?
2. Elderly drivers appear to have problems when making left turns (and right turns) at signalized and stop-controlled intersections and when starting from a stop at stop-controlled intersections. Is this due to decreases in gap judgment skills, decreases in perceived visual field, distraction level, or other causes?
3. Most intersections are unsignalized (particularly in rural areas). Current design criteria for intersection sight distance have been questioned in recent years. What are the characteristics of driver gap acceptance (for elderly as well as other drivers) by various traffic and geometric conditions that can be used to reexamine current sight distance criteria?

INTERCHANGES

In contrast to an at-grade intersection in which two roads cross at the same level, an interchange is a system of interconnecting roadways that provides for movement of vehicles from highways which cross each other at different elevations -- one crossing above the other. Many interchange configurations are defined in the American Association of State Highway and Transportation Officials Policy on Geometric Design of Highways and Streets. As shown in Figure 7, the designs include cloverleafs, variations of each of these major types, resulting in twelve or more interchange types that are recognized as "standard" for engineering design. Safety research is focused primarily on the most common types -- diamonds and cloverleafs.

As shown in Figure 8, the components of a cloverleaf interchange include the two main roadways, which are referred to as the "main line" and the crossing route, and a series of ramps which allow turning vehicles to get from one of the roadways to the other. The outer connector ramps allow vehicles to turn right from one roadway and enter on the right side of the other, while the inner loop ramps allow vehicles to exit right in order to make what would be a left-turn maneuver at an at-grade intersection. The area between the ends or terminals of the inner loop ramps is known as the weave section, since vehicles which are entering one inner loop must "weave" in and out with vehicles exiting from the other nearby inner loop. Additional components of interchanges include the acceleration and deceleration sections that are found at the ends of each of the outer connection ramps.

With respect to overall geometric design, some research indicates that urban interchanges have a higher accident rate per million vehicles than do rural interchanges in general, particularly at entrance ramps (i.e., the end of a ramp where a vehicle is entering the main line or crossing route). This higher rate is probably due both to increased conflicts resulting from the increased traffic flow and also to the inadequate length of the acceleration and deceleration lanes that are usually found in urban areas where space for interchange design is limited.

It is fair to say that most of the accident problem with interchanges is related to the design of the inner and outer ramps. With respect to the inner loop ramps, research indicates that the sharper the ramp and the more traffic that is on it, the higher the accident rate. For the outer connector ramps, exit ramps (where vehicles are leaving a roadway) appear to have a higher accident rate than do entrance ramps. This is probably due to the large numbers of vehicles that exit the main line and enter off-ramps at high speeds and must then decrease their speed rapidly to safely traverse the ramps. It also appears that upgrade off-ramps have lower accident rates than do downgrade off-ramps. Thus, because most of the traffic entering ramps usually comes from the freeway rather than from the crossing route, it is desirable for the freeway to always pass underneath the crossing route such that all exit ramps from the freeway are going upgrade rather than descending.

There are also interchanges in which traffic must exit from a roadway on a left-side ramp. Research has shown that such left-side ramps have higher accident rates than do right-side ramps. This is probably because they violate driver expectations of the side on which ramps should be diverging and merging.

One of the key issues related to freeway interchange design involves heavy truck accidents at interchanges. It appears that truck accident rates are higher on both loop and outer ramps than are the rates of other vehicle types, and that these increased rate are due both to truck skidding and to truck rollover crashes.

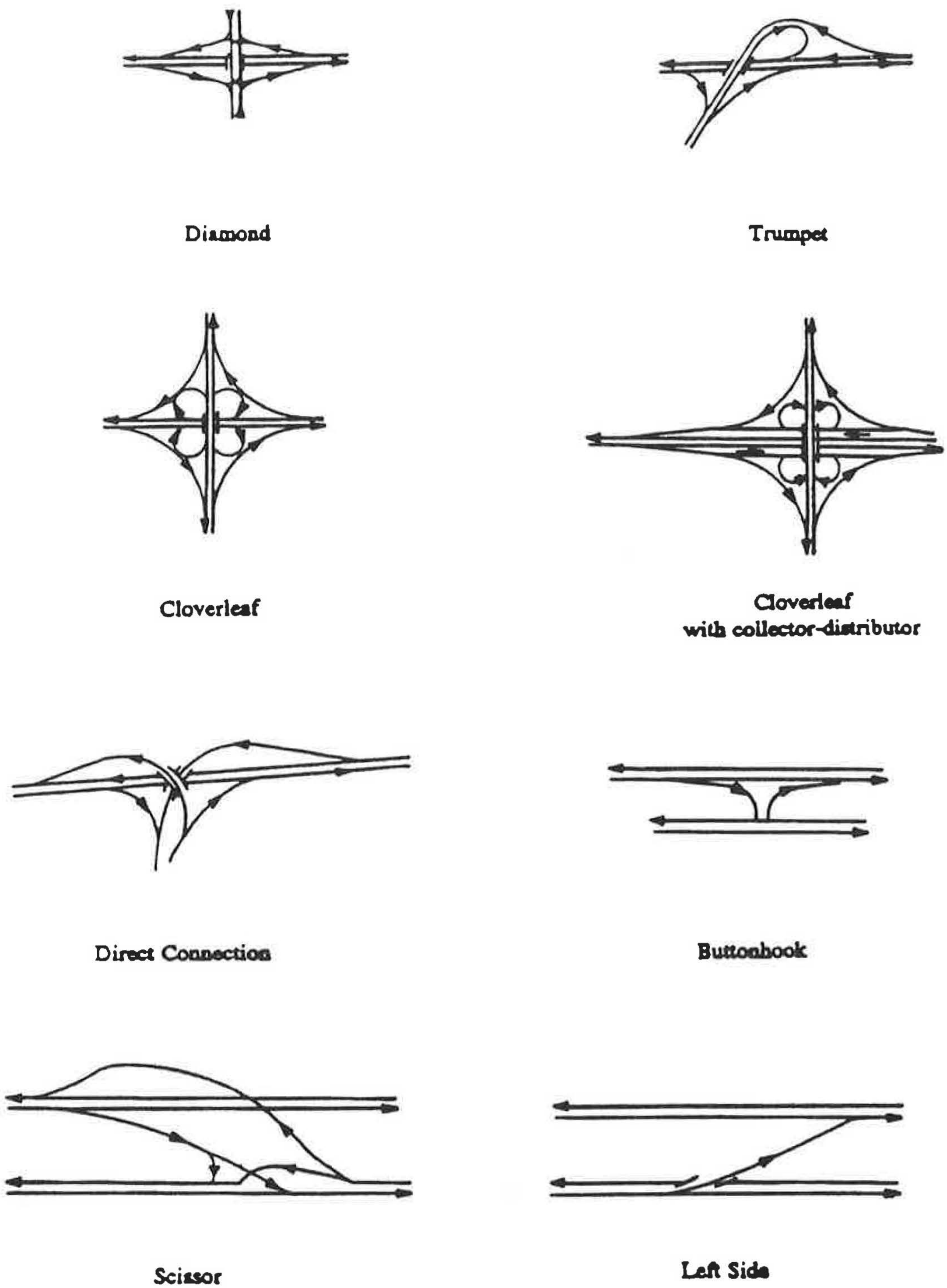

Figure 7. Typical interchange designs.

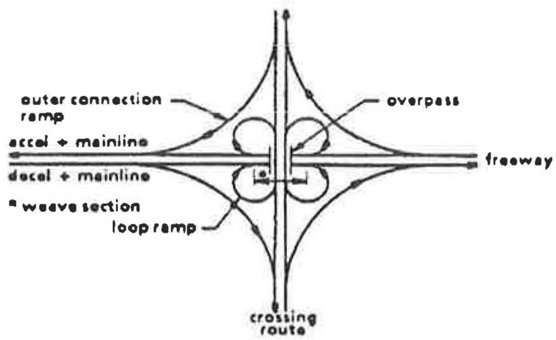

Figure 8. Cloverleaf interchange elements.

Finally, in urban areas where interchanges must carry very high volumes of turning traffic, it appears that the use of collector/distributor roadways enhances safety. These roadways require all turning vehicles to exit the main line prior to the interchange proper and allow these vehicles much longer diverge and merge areas at lower speeds than is the case with the standard cloverleaf. While such interchanges may violate, to some extent, driver expectation of what a standard (cloverleaf) interchange looks like, it appears that the benefit from the separation of the inner-loop merging and diverging vehicles from the main flow on the freeway outweighs any problems resulting from unmet driver expectations.

Thus, with respect to interchanges, the human factors issues of interest are as follows:

1. It has been hypothesized that elderly and inexperienced drivers have problems merging at interchange on-ramps. Is this true, why?
2. Many drivers have problems in the merge area on cloverleafs when attempting to merge right to exit. What are the major human factors causes of these particular problems?
3. Heavy trucks appear to experience increased risk of crashes on interchange ramps. Are there perception, judgment, or other problems which lead to these safety problems?
4. Many drivers have problems in the merge area on cloverleafs when attempting to merge right to exit. What are the major human factors causes of those problems?

CONCLUSION

Highway safety is influenced heavily by highway design features and the interaction of various human factors on these features. Roadway design features include cross-sectional design (lane and shoulder width and type, roadside features, highway bridges, median design, multilane design alternatives), horizontal and vertical alignment, pedestrian and bicycle facilities (sidewalks, bike lanes, and paths), intersection design, and interchanges. Safety relationships have been developed with many, but not all, of these roadway design elements. However, much human factors research is needed to help us better understand road users so we can design and upgrade roadways for enhanced safety and mobility.

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RECENT ACCIDENT TYPOLOGY RESEARCH

Recent Research in Developing Accident Typologies

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INTRODUCTION

The identification of Intelligent Vehicle/Highway Systems (IVHS) as a national priority has rekindled interest in collision avoidance. Collision avoidance, however, is much broader than IVHS. Similarly, the topic of this symposium, Human Factors in Highway Safety, is also much broader than IVHS. A positive aspect of this new IVHS interest may be that the seemingly unlimited potential of advanced technology will stimulate us to take a new approach to these issues. Recently, we at UMTRI have been looking at existing accident data to see if new approaches could be developed that would provide information to support the development of advanced technologies for collision avoidance. Such an approach necessarily focuses on the precollision events, which is also the area dominated by human factors. Thus, the Federal Highway Administration felt that even though the original work was intended to address vehicle-based collision avoidance technology, the findings may also be relevant to this conference. The conference break-out groups are organized around four collision types, taken more or less, from a collision typology presented in a recent paper (Campbell, 1991). My presentation here is intended to summarize the development of the typology and provide available accident data on the four collision types that have been selected as the focus for this workshop.

The objective of collision avoidance research is to identify countermeasures that will prevent the collision. Thus, the focus is on the precollision sequence of events to identify opportunities for intervention. There is a problem with using existing accident data for this research because the focus of the accident data elements is primarily on the most harmful event. While this focus is appropriate for the analysis of vehicle crashworthiness, the most harmful event is often *not* the initiating event. Collision-type coding based on the most harmful event can be misleading if one tries to infer the precollision events. The approach that will be described here tries to work around the limitations of existing accident data. The objective is to group collisions with common precollision characteristics.

METHOD

The approach seeks to develop a list of collision situations ranked according to the potential benefits of collision avoidance and a characteristic sequence of events for each. This information will support the identification of opportunities where intervention has the potential to prevent or mitigate the collision and the nature of the required intervention. The steps in the proposed method are summarized below.

1. Define relevant collision situations (types).
2. Rank the collision types by the potential benefits of collision avoidance.
3. Identify contributing factors associated with each collision type.

4. Characterize each collision type in terms of the physical sequence of events leading to the impact.
5. Identify opportunities in the sequence of events where intervention has the potential to prevent or mitigate the impact.

The first issue is to identify the characteristics that will form the basis of the definition of collision types. This choice will be influenced by the collision avoidance countermeasures of interest. For example, the typology that has been suggested was intended to address vehicle-based collision avoidance technology (Campbell, 1991). Consequently, it was presumed that the precollision relative position of the vehicles was fundamental. Once the collision types have been defined, it is useful to rank them in some way. The most obvious ranking is based on prevalence, or how frequently the collision type occurs. The potential benefits of preventing a very common collision situation will be much greater than the benefits of preventing an event that seldom occurs. Other measures may also be considered in ranking the collisions, such as the probability of injury or, perhaps the risk of accident involvement. The next step in developing a comprehensive picture of the collisions to be addressed is to identify driver, vehicle, roadway, and environmental factors that are associated with each collision type. The associated factors provide a description of the environment in which each collision type occurs. The last two steps in the approach address characterizing the physical sequence of events prior to the collision and then examining this sequence to identify opportunities for intervention. This approach is described more fully in the referenced paper (Campbell, 1991). For now, I want to proceed to the definition and selection of the four collision types identified by the organizing committee as the focus of the remainder of this workshop.

SELECTED COLLISION TYPES

In order to determine the precollision situation (as opposed to the orientation at the time of the most harmful impact), the following roadway and traffic flow variables were used to define the typology. The typology shown here has been refined somewhat in an effort to be more responsive to the workshop objectives. The single-vehicle accidents have been classified by object struck; they can then be characterized as on or off the roadway. Also, a distinction between signed and signalized intersections has been omitted here. The distribution of collisions into the categories defined by this typology is shown in the following tabulation from the 1984-86 CARDfile. The tabulations are based on a 5% sample of the three-year CARDfile that includes 55,186 single-vehicle accidents and 124,329 two-vehicle accidents. The tabulation is based on counts of accidents, not on the number of vehicles involved in the accidents.

ACCIDENT TYPOLOGY

Single Vehicle
- Fixed Object
- Pedestrian/Pedacyclist/Animal
- Rollover
- Parked Vehicle

Two-Vehicle Intersection
- Crossing Paths/Same Direction/Opposite Direction
- Both Straight/One or Both Turning

Two-Vehicle Nonintersection
- Same Direction
- Opposite Direction
- Driveway/Parking

The most prevalent collision type is the single-vehicle, fixed-object impact. These collisions occur off the road, and leaving the roadway is the initiating event. Since this is true of most single-vehicle rollover accidents as well, these two collision types have been combined and designated as Group III, Run-off-the-Road, of the selected collision types for this workshop. The Run-off-the-Road group represents 18% of all police-reported accidents. The other three collision groups selected are all two-vehicle accidents. Group I combines two situations that usually result in a rear-end collision. These are the nonintersection collisions between two vehicles initially traveling in the same direction and collisions of two vehicles at an intersection when both are traveling in the same direction, but neither intends to turn. Together, this two types form Group I, Rear-End, and represent 22% of all accidents. Group II is composed of two other intersection collision types. These are collisions between two vehicles on the crossing legs of an intersection when both intend to go straight through the intersection and collisions between two vehicles traveling in opposite directions through an intersection when one or both intend to turn. These two intersection collision types represent 19% of all accidents. The last group, Group IV, Head-On, represents only about 4% of all police-reported accidents. However, the probability of fatality is much higher for this collision type: it accounts for about 20%

of fatalities. In combination, the four collision groups selected for this workshop represent about 63% of all police-reported accidents. The four selected collisions groups are summarized in the following table.

SELECTED COLLISION GROUPS

I.	Rear-End	22%
	Nonintersection/same direction	11%
	Intersection/same direction/both straight	10%
II.	Intersectional	19%
	Crossing paths/both straight	13%
	Opposite direction/one or both turning	7%
III.	Run-off-the-Road	18%
	Fixed object	16%
	Rollover	3%
IV.	Head-On	4%
	Nonintersection/opposite direction	4%
	Intersection/opposite direction/both straight	1%
	TOTAL	63%

ASSOCIATED FACTORS

The factors that affect the driver, vehicle, roadway, and environment vary for the different collision types. Once collisions have been grouped, as in the above typology, the next step is to identify the factors associated with individual collision types. Drawing from previous work, driver age, gender, and impairment (alcohol); lighting (day/night); and road surface condition (snow or ice) were examined for association with the selected collision groups. The association of each these factors with each of the four selected collision groups is described in the following sections.

Group I, Rear-End. Note from the distribution of accidents in the collision typology that the percentage of rear-end accidents is about equal between the two types selected: 10% intersection, same direction both straight and 11% nonintersection, same direction. However, the general environment is different in that the intersection collisions are predominantly in urban areas, whereas the nonintersection collisions are predominantly rural. The percentage of these accidents associated with the factors identified above is summarized in the following table:

ASSOCIATED FACTORS: REAR-END GROUP

Alcohol	7%
Darkness	10%
Snow or ice	7%
Excessive speed with low friction	8%

The percentages for the first three factors shown--alcohol, darkness, and snow or ice--are essentially the same as the percentages observed for all two-vehicle accidents. Thus, none of these factors shows any significant association with the rear-end collision group.

However, excessive speed with low roadway surface friction is coded for this group about twice as often as for all two-vehicle accidents, 8% versus 4%, respectively. Overall, none of the factors listed above was coded for 75% of the rear-end group. In addition, no particular associations were observed with age or sex. Previous researchers have identified "inattention" as a contributing factor in rear-end collisions, but without more detail this characterization does little to expand on the essential nature of this collision group.

Group II, Intersectional. Group II also combines two collision types from the typology. The first of these, crossing paths, both straight, is about twice as large as the second, with about 13% of all police-reported accidents as compared with the opposite-direction, turning type of accident, with 7%. The associated factors will be examined separately for these two subsets of Group II.

The associated factors for the intersection, crossing paths, both straight collision type are summarized below.

ASSOCIATED FACTORS: INTERSECTIONAL GROUP--CROSSING PATHS, BOTH STRAIGHT

Alcohol	5%
Darkness	7%
Snow or ice	6%
Signal	35%
Sign	46%

Like the rear-end group, alcohol, darkness, and slippery roads are not overrepresented in this group and are not factors in a significant percentage of these accidents. However, the distribution between signed and signalized intersection is of interest. Significant percentages of these collisions occur with both types of control.

A review of police accident reports for samples of accidents from this group at signed as compared with signalized intersections revealed some interesting differences. At the signalized intersections, nearly all of these accidents were the result of a driver's entered the intersection against a red light. There was no strong pattern in the age of these drivers, although there was some overrepresentation of older drivers. The situation was much different at the signed intersections. Here there were two distinct subsets. In approximately 45% of these collisions, a driver failed to stop at the sign, proceeding into the right-of-way of the other driver. Forty-five percent of the drivers that failed to stop were under the age of 25, a very strong overrepresentation of this age group. In contrast, the other subset (41% of the collisions at signed intersections) was characterized by a driver's first stopping at the sign and then proceeding into the right-of-way of the other vehicle. Sixty-nine percent of the drivers that first stopped and then pulled out in front of another vehicle were over age 60--again a very strong overrepresentation of this age group and a very different kind of error.

Associated factors for the opposite-direction, turning, collision type are summarized below.

ASSOCIATED FACTORS: INTERSECTIONAL GROUP--OPPOSITE DIRECTION, TURNING

Alcohol	6%
Darkness	8%
Snow or ice	2%
Signal	49%
Sign	8%

The predominant factor here is that nearly half of these collisions occur at signalized intersections and very few at signed intersections. A review of police accident reports indicates that the most common situation is one in which a vehicle makes a left turn across the path of the other. Age distributions were examined for the turning driver as compared with the driver going straight through. About 19% of the turning drivers were over 56, while only 9% of the drivers going straight through were over 56. The older drivers are overinvolved as the turning driver by about a factor of 2, but they still make up only 20% of the offending drivers. Clearly this error is not limited to the older driver.

Group III, Run-off-the-Road. The largest single category of the typology, 16% of all police-reported accidents, is the single-vehicle, fixed-object impact. Single-vehicle rollover accidents represent another 3% of all accidents. Running off the roadway precedes each of these collisions. The associated factors for this group are quite striking. The environmental factors demonstrate a predominance of rural roads at night, with slippery road surfaces in 17% of these accidents. With regard to the driver, this collision type is prevalent amoung young men. Alcohol impairment is indicated for about one-quarter of these drivers. The associations of these factors are summarized in the following table. Here is a group that includes almost 20% of all police-reported accidents and is apparently a consequence of social factors that shape young male driving behavior.

ASSOCIATED FACTORS: RUN-OFF-THE-ROAD GROUP

Rural	70%
Age 16-25	50%
Male	70%
Alcohol	26%
Darkness	39%
Snow or ice	17%
Excessive speed with low friction	16%

Group IV, Head-On. This group also shows some overinvolvement of young, male impaired drivers, but not nearly to the same extent as in the previous group. Here, if the impaired drivers are omitted, there is no overinvolvement by age or sex among the remaining drivers. Slippery roads play a larger role, 21% more in this group than in any of the previous groups, although excessive speed is identified less often than in the ran-off-road accidents. Perhaps the limited visibility in situations producing slippery roads is a factor in these collisions. It should also be noted that 50% of the accidents in this group did not involve any of the factors identified in the table below. While there is clearly some overinvolvement in this collision type with both degraded drivers and a degraded environment, this collision often occurs with both "normal" drivers and driving conditions.

ASSOCIATED FACTORS: HEAD-ON GROUP

Alcohol	15%
Darkness	19%
Snow or ice	21%
Excessive speed with low friction	10%

CONCLUSIONS There are inherent problems with using existing accident data to study collision avoidance in general and the role of human factors in particular. First, there is the problem that existing data provide little information on the precollision situation or events. Additionally, there is the problem that the perceptions, decisions, and actions of the human leave little evidence from which to infer the influence of these factors. However, I am not inclined to dismiss the study of accidents as a way to expand our current understanding of the role of the driver in collision avoidance. Since accidents are *the* event we wish to prevent, it seems necessary to focus part of our attention there.

A related issue is the notion that there is a difference between "normal" driving and driving behaviors that result in accident involvement. It is easy enough, after the fact, to identify particular actions, or lack of action such as "inattention," on the part of the involved driver as the "cause" of the accident. But so far, such information has not been particularly useful in preventing, or reducing, drivers' tendencies to make these errors. If "normal" driving is considered to be error free, or accident free, or something that is simulated in a laboratory, or controlled experiments on the road, then there would seem to be some question as to what this has to do with accidents. Real driving often seems to be quite tolerant of occasional driving errors, or less-than-optimal performance. If the objective is to prevent accidents, then it would seem necessary to try to determine whether there are situations, meaning the combination of the driver's performance and all of the other pertinent factors that define the driving environment at that moment, that have a significantly elevated risk of accident involvement. The opportunities for collision avoidance would seem to come from an understanding of the demands in those situations. These demands may or may not be similar to the demands in the relatively low-risk situations that make up the vast majority of our driving experience.

Rather than abandon the study of accidents, I think it is necessary to work backwards from the collision to the precollision events. It is my hope that this workshop will conclude that the study of accidents needs to be expanded to better address the precollision events in order to provide a bridge between the accident and events that elevated the risk of accident involvement. Such information would seem to be important to prioritizing human factors research areas for the purpose of collision avoidance. I would urge the working groups to review their problem statements as they are being developed to ask what has been assumed about the accident experience. What is the assumed precollision sequence of events? What are the assumed physical mechanisms responsible for each event? What has been assumed about the role of the driver in the sequence of events? I believe that the research proposals should include a verification of the specific aspects of the assumed precollision sequence of events that form the basis for each human factors research area identified. My concern is that a human factors research agenda will be based on intuitive definitions of the problem as opposed to the actual highway experience.

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BREAK-OUT SESSION REPORTS: RESEARCH PROBLEM AREAS

REAR-END COLLISIONS

REAR-END COLLISIONS -- 1

Title: Definition, Measurement, and Control of Driver Attentional Impairment in Specific Traffic Situations
Problem: Inattention (including difficulty with divided attention, allocation of attention, multitask performance) is considered a leading contribution to rear-end collisions. Conditions that impair a driver's attention include those that are temporary (adaptation, fatigue) as well as those due to functional deterioration. We currently lack a definition of what constitutes attentional impairment, ways of measuring it, or means of controlling it.
Objectives: (1) Undertake dynamic laboratory simulation studies systematically varying conditions

believed to be associated with attentional impairment, and employing subjects with known attention-related impairment to assess the interactive relationship of both to measures of attentional performance. (2) Conduct highway studies to verify relationships discovered in laboratory, and to validate laboratory measures for assessment of attentional impairment and to test the impact of warnings on restoring attention. (3) Assess alternative means of controlling attentional impairment, such as work-rest cycles, medication, instruction, and restriction.
Key Words: Attention; rear-end collisions
Related Work: Useful field of view.
Cost: $600,000; 2-3 years
Implementation: Develop specific usable countermeasures to control attentional impairment.

REAR-END COLLISIONS -- 2

Title: Methods for Safety Surrogate Identification in Specific Traffic Situations
Problem: Accident data are limited as measures of safety in at least two major ways: (1) those data that are collected do not usually define causative, precrash factors, and (2) although accidents represent a commonly accepted metric of safety, their lack of predictability and frequency decrease the utility of accident data as diagnostics for human factors causes. Safety surrogates (such as time headway distributions), however, have the quality of higher frequency of occurrence that can be related to near-miss events under in-vehicle and simulation conditions. This increases safety data reliability at the expense of safety data validity. The challenge, therefore, is to develop a method for identifying safety surrogates that have high validity under specified operating conditions.
Objectives: 1) Develop methods to identify valid safety measures that can be used in laboratory and field studies and experiments, 2) Use large-scale vehicle instrumentation to validate surrogates against accidents and use high accident sampling techniques, 3) Improve methods for capturing human factors contributions in accident reports.
Key Words: Safety measures; accident reports
Related Work: NASA's Aviation Safety Reporting System; Conflicts Measurement Techniques; In-depth, on-site Accident Reconstruction (e.g., Indiana Tri-level MDAI)
Cost: $500,000 - $1 millon over 5 years
Implementation: Develop safety surrogates to improve research effectiveness and efficiency.

REAR-END COLLISIONS -- 3

Title: Factors Influencing the Selection of Vehicle Headways
Problem: Rear-end collisions may result from drivers who follow too closely; however, the reasons drivers select particular following distances are not known. One hypothesis is that due to lack of feedback, drivers may unconsciously adopt increasingly shorter following distances. Alternatively, in congested traffic, drivers may deliberately select short following distances because of impatience or in order to prevent other drivers from moving into their lane. To the extent that drivers are unaware of their following distances, there may be opportunities to increase their awareness through automatic headway monitoring and alerting.
Objective: Determine factors that influence drivers' selection of following distances. Approach will include the unobtrusive measurement of headways under a variety of traffic conditions for different categories of drivers/vehicles. Results will be used to generate specific hypotheses to be tested experimentally, either on a closed course or on the road. Experimental work will determine the extent to which headways are insufficient and to what extent drivers consciously select headways. Focus group work with male/female, older/younger drivers will be useful in defining the problem.
Key Words: Vehicle headways; car following; driver risk-taking; safety margins; angular size changes; size perception
Related Work: Two-lane road studies on overtaking behavior.
Cost: $400,000 over 2 years
Implementation: Identify the extent to which countermeasures should be oriented toward the driver (alerting devices) or the roadway (to improve traffic flow, reduce congestion). Further development of selected countermeasures will be required.

REAR-END COLLISIONS -- 4

Title: Perceptual Factors in Closure Rates
Problem: Rear-end accidents occur when the trailing driver fails to see, judge, and take action to avoid the lead vehicle. Assuming that the lead vehicle is visible, what are the perceptual factors within the person-system-environment that support accurate judgments of closing speed and distance?
Objective: Identify and describe the critical factors in perception of relative velocities and proximal distances

between own vehicle and immediate leading vehicle. Conditions of interest include lead vehicles at constant, increasing, decreasing, and zero velocities with trailing vehicles at non-zero velocities and decreasing spacing. Do particular vehicle-environment configurations reduce accuracy of perception of closure? What is the effect of lowered visibility related to atmospheric phenomena (rain, snow, fog) and darkness? What is the effect of lead vehicle characteristics? The approach will include literature surveys, analyses, laboratory research (part-task simulation), full-motion simulation, and field studies (controlled and natural environment). Measures will include time to perceive onset of closure (a change in relative velocity between lead and trailing vehicle), accuracy of perception of active rates and effective utilization of perception.
Key Words: Perception; psychophysics; rear-end collision; overtaking
Related Work: Adverse visibility; headway election; attentional direction
Cost: $250,000 per year at the start of a multiyear project phased in accordance with proposed approach
Implementation: Provide recommendations for minimum essential cues supporting accurate perception of closure rates in terms of person, vehicle, and environment. Support selection of approaches to ameliorate rear-end collisions.

REAR-END COLLISIONS -- 5

Title: The Contribution of Environmental and In-Vehicle Distractors to "Driver Inattention" Leading to Rear-end Collisions
Problem: Rear-end collisions are often coded by police officers as being caused by "driver inattention". The driver's need to attend to his primary task may be compromised by distractors both inside and outside of the vehicle and by factors both relevant and irrelevant to the driving task. Irrelevant, external (environmental) distractors include billboards, whereas in-vehicle irrelevant distractors include cellular phones and entertainment systems. The proliferation of traffic control devices (especially signs and signals) and the lack of standardization of such devices across jurisdictions are examples of relevant environmental distractors, whereas advanced instrumentation and controls, improperly designed or implemented, represent relevant in-vehicle distractors. It is believed that these types of distractors may contribute in a substantial way to 74% of rear-end collisions whose causation is not clearly categorized.
Objective: Assess the relative contribution of in-vehicle and environmental relevant and irrelevant distractors to driver inattention. Approaches will include simulated and on-the-road driving tasks using various dependent measures of attention, such as eye scanning behavior.
Key Words: Distraction; inattention; sign proliferation; outdoor advertising; environmental; in-vehicle
Related Work: Studies on driver response to IVHS technologies; cellular phone use; outdoor advertising; sign comprehension and decision making.
Cost: $600,000; 3 years
Implementation: Identify the nature of driver distractors such that guidelines and countermeasures can be developed in subsequent efforts.

REAR-END COLLISIONS -- 6

Title: Communication of Advisory Warnings Regarding Traffic Flow, Traffic Speed, or Environmental Hazards Impeding Traffic Progress
Problem: Driver awareness of impending changes in the speed or continuity of traffic flow and of hazards or impediments that might be encountered is important for the maintenance of appropriate headway and the initiation of slowing and/or stopping appropriately when the roadway is obstructed. Providing explicit advisory messages that communicate such information has potential relevance for the prevention of rear-end (as well as other) crashes. Such messages can be displayed via roadside signs and displays or via in-vehicle electronic displays. Influencing driver behavior through warnings is an appealing means of communication. Little is known about communication effectiveness in this situation, and such efforts must be based on empirical research.
Objectives: Determine the kinds and categories of advisory messages regarding traffic flow that are most appropriate for roadside and in-vehicle displays; thoroughly evaluate relevant message characteristics, including message length and complexity, reading speed/display rate, reading level, etc.; determine characteristics for roadside and in-vehicle displays, including display type, placement, and physical properties (size, brightness, etc.); and evaluate the capacity of roadside and in-vehicle advisory messages to influence traffic speed, vehicle separation, and accidents.
Key Words: Warning messages; traffic advisories; in-vehicle displays; variable message signs

Related Work: IVHS information display work; variable message sign research.
Cost: $100,000 - $200,000 per year over 2 years
Implementation: Develop guidelines and standards for roadside and in-vehicle traffic advisory warnings and display systems.

REAR-END COLLISIONS -- 7

Title: Instrumented Highway to Measure Speed and Time Headway Election as a Function of Environmental Variables
Problem: There is a paucity of safety data from large-scale, controlled field experiments and studies that investigate the relationship between environmental and highway system design variables and rear-end collisions. Accident data currently available are after the fact and anecdotal. Therefore, an empirical, hypothesis-driven approach is needed to derive causal relationships between design and environmental variables and highway safety.
Objective: Obtain empirical research data with high external validity related to highway safety, including the following: (1) assigned field study variables: friction coefficients, time headway distribution, visibility, density, flow speed, etc.; (2) experimental variables: control devices, changeable message signs, roadside radio, sign content, format, placement, etc.; and (3) approach: collect long-term pre- and post-change data and perform professional accident investigations.
Key Words: Instrumented highways; rear-end collisions; safety measurements; environmental factors
Related Work: FHWA Maine facility; NCHRP and FHWA in progress. Studies on geometric design and highway safety standards.
Cost: multi-million dollar; partnership options
Implementation: Possibly generate highly valid and reliable data supporting cause-and-effect relationships among environmental, design, and safety measurement variables.

REAR-END COLLISIONS -- 8

Title: Effects of Adverse Visibility Conditions on Driver Overtaking Behavior and Associated Countermeasures
Problem: Reduced visibility from darkness, rain, fog, and dust can affect driver detection and discrimination of vehicles ahead in overtaking situations. Reduced time headway and increased time headway variability and high closing rates characterize these conditions. There is a need to examine vehicle, TCD, and highway lighting relative to daytime conditions and special delineation countermeasures needed to offset adverse environmental effects.
Objective: (1) Measure the effect on driver overtaking performance measures of reduced visibility for cars and trucks. (2) Test the effect of such countermeasures as (a) changeable message signs for speed; (b) pavement markers and chevrons on road surface at fixed intervals to help driver select appropriate speeds; (c) better rear lighting and reflectivity (e.g., fog lamps for cars and trucks); and (d) highway lighting.
Key Words: Reduced visibility; driver overtaking behavior; vehicle detection; fog; night; rain
Related Work: See relevant European work.
Cost: $300,000 per year over 3-5 years
Implementation: Develop countermeasures to improve the safety of driver overtaking behavior under adverse visibility conditions.

REAR-END COLLISIONS -- 9

Title: Driver Perceptions, Decisions, and Responses to Congestion, Including Impending/Anticipated Delay
Problem: Driver responses need to be determined for a wide range of recurring and nonrecurring delays and congestion factors (e.g., reduced time headway). Driver perceptions and decisions that lead to these responses need to be determined.
Objective: Determine the negative driver responses that result from congestion and delays. Identify candidate measures for adjusting the highway design to better control and/or accommodate their responses. Determine candidate measures for adjusting driver perceptions and reactions to congestion, especially recurring short delays (i.e., more information, training). Specifically, the length of signal cycles, the length of the yellow change phase, lane changing, and queue jumping should be studied.
Key Words: Driver perceptions; driver decisions; driver responses; congestion; delays
Related Work: "shock wave" phenomenon research; work on effects of increased time headway on flow stability; FHWA work on navigational efficiency.
Cost: $300,000; 18 months
Implementation: Quantify and evaluate how driver responses effect highway efficiency and safety; analyze driver responses and behaviors to recurring and nonrecurring delays and congestion; compare driver actions, decisions, choices, etc. with current traffic flow and congestion safety measures.

REAR-END COLLISIONS -- 10

Title: Critical Incident Study of Rear-End Near Misses
Problem: Existing crash data provide little useful information about the traffic conditions, driver behaviors, and vehicle actions in the seconds prior to the crash. As a result, human factors safety problems and possible countermeasures are difficult to identify.
Objective: Supplement existing data by collecting information from a sample of drivers about their near misses (i.e., critical incidents). This research would evaluate alternative techniques for collecting data about near misses, identify the types of near-miss information of interest, develop a sampling and data analysis plan, and implement the plan. The method used to obtain reliable and timely information that is couched in a consistent and useful format is critical.
Key Words: Human factors; critical incidents
Related Work: Aviation critical incident techniques
Cost: $400,000; 2 years
Implementation: Identify the extent and nature of potential safety problems as well as possible countermeasures.

REAR-END COLLISIONS -- 11

Title: Effect of Navigational Uncertainties on Hazardous Driving
Problem: Unfamiliar drivers are increasingly confronted with multitask and information overload decision-making situations which involve negotiating difficult geometrics and traffic configurations. This combination of factors competes with navigation and causes driver uncertainty and hazardous situations such as backed-up traffic created by the need for a decision upstream where there is no relevant information.
Objective: Determine the contribution of driver uncertainty to hazardous driving behavior. Determine measures of safety related to this hazardous behavior and their association with specific types of accidents. Determine the relevance of advanced navigation aids as countermeasures.
Key Words: Navigation; driver error; decision making; geometrics; uncertainty; safety
Related Work: positive guidance; information transmission techniques; diagrammatic signs; decision sight distance.
Cost: $300,000 over 5 years
Implementation: More effective design of on-road and in-vehicle navigation systems based on a better understanding of the importance of navigation-based errors and resulting hazards.

Rear-End Collisions -- Additional Problem Titles

Design Failures Due to Traffic Backups

Minimum Headway Acceptance As a Function of Roadway Classification/TCDs

Computer Simulations of Rear-End Collisions

Truck Detection and Visibility Under Adverse Conditions

INTERSECTIONAL ACCIDENTS

INTERSECTIONAL ACCIDENTS -- 1

Title: Human Factors Considerations in Intersection Design and Operation
Problem: There have been no attempts to integrate and synthesize information that is known about driver behavior at or in intersections. Without a critical review of what is currently known about intersections, drivers, and vehicles, it is not possible to formulate an appropriate plan for future research. A related problem is the interdisciplinary nature of research in this area. There is a need for a review that will synthesize research on driver factors, vehicle factors, and roadway factors.
Objective: Produce a general literature survey and future research plan for the intersection problem. This must include a synthesis of the interdisciplinary work that describes what is currently known about intersections and about individual and group behavior at intersections. For example, this literature review must include research (both survey and empirical) and accident analyses that have been conducted in the traffic engineering and behavioral science fields. The summary should include a review of information associated with driver behavior at intersections, such as (a) type of traffic control devices (delineation, signs, signals), (b) interaction with traffic and pedestrians, and (c) decision making under time pressure and uncertainty.
Key Words: Driver behavior, gap acceptance, decision making at intersections, exposure and accident risk; demographics

Related Work: Ongoing FHWA intersection projects and NCHRP Project on Intersection Sight Distance.
Cost: $500,000
Implementation: Develop a research guide summarizing and synthesizing previous research, and identifying gaps in the knowledge which require further investigation. Develop a preliminary intersection design handbook for use by traffic engineers and designers.

INTERSECTIONAL ACCIDENTS -- 2

Title: Response to Traffic Control Devices as an Aspect of Group Behavior
Problem: Responses to traffic control devices (stop signs, traffic signals, etc.) vary from community to community and from time to time. Overuse of signs is believed to breed disrespect. Allowing right turn on red was thought to degrade obedience to the red phase. Use of long intergreen intervals is thought to promote amber encroachment, etc. The question is whether these traffic engineering actions do promote such adverse group behavior and, if so, what interventions would offset such effects.
Objective: Describe the differences in norms of compliance to traffic control devices in different communities. Explore what factors may be responsible for such differences. Examples of research areas include the following: (a) determine whether in fact the gradual increase of stop sign use is associated with increased violations and whether the removal of stop signs increases obedience; (b) examine the effect of other possible factors which influence the evolution of obedience of traffic control devices; (c) examine what differences exist in the inclination to encroach on the amber and red phases of signalized intersections in different communities, and explore what factors may cause such differences; (d) examine whether long intergreens are associated with more amber encroachments; (e) determine whether the increase in intergreen duration is gradually eroded by increased encroachments.
Key Words: Intersections; traffic control devices; group behavior
Related Work: FHWA effort on traffic signal compliance.
Cost: $300,000; 4 years
Implementation: Develop TCD design and implementation to promote driver compliance.

INTERSECTIONAL ACCIDENTS -- 3

Title: Group Influences in Traffic
Problem: Road user behavior is influenced not only by inherent abilities and traits such as vision, reaction times, information processing, risk taking, etc., but also by the culture of driving with which the road user is surrounded. Thus, speed choice and the decision to obey a traffic sign or to enter the intersection the on the amber signal are partly influenced by group norms of behavior. Both the prevailing norm and the variability around it influence the individual's behavior. These cultural norms are constantly evolving and are shaped partly by decisions which mold the physical and operational aspects of the road system. The same norms also affect system safety.
Objective: Examine how group behavior in traffic evolves over time and how it differs from place to place. Determine what factors influence the evolution of norms. Seek theories and models that explain changes in group behavior. Find how group behavior can be managed by design and operational measures, sanctions, rewards, and other means. This problem statement is viewed as a series of individual studies or a single multiphase study. For example, Phase 1 could develop and validate models of group behavior and Phase 2 would translate the output of those models into techniques for use by traffic and design engineers.
Key Words: Group dynamics; social behavior; violations
Related Work: Related work in group dynamics and social behavior.
Cost: $3 million for a multiphase program
Implementation: Develop methods for managing group behavior, including highway design and operation, sanction, and rewards. With better understanding of the phenomena leading to improved design and controls, one can expect reduced violations and accidents.

INTERSECTIONAL ACCIDENTS -- 4

Title: Decision-Making at Intersections
Problem: It is not known how drivers base their decisions to execute a maneuver through an intersection. A perceptual/cognitive task analysis must be conducted to determine the variables which are relevant to these decisions. The analysis must consider relevant literature in behavioral and driver data bases. Individual and group differences in risk taking and situation assessment need to be addressed.

Objective: Develop a better understanding of driver decision-making at intersections to serve as a basis for design and operational improvements at intersections.
Key Words: Decision-making; risk taking; risk perception; individual differences; gap acceptance; situational awareness
Related Work: Ongoing FHWA intersection research.
Cost: $500,000
Implementation: Develop guidelines to increase driver safety at intersections through highway design and operational improvements.

INTERSECTIONAL ACCIDENTS -- 5

Title: Definitive Analysis of Driver Performance of Left-Turns at Signalized Intersections
Problem: A definitive analysis regarding driver behavior during left-turn maneuvers has not been conducted. Such an analysis will produce a clearer understanding of how drivers with different capabilities negotiate signalized intersections. This analysis will result in a comprehensive model which includes the driver, the vehicle, traffic control devices, environmental factors, and highway configurations.
Objective: Develop a model and taxonomy for left turns at signalized intersections that will describe how drivers correctly (and incorrectly) perform the tasks of negotiating intersections.
Key Words: Driver demographics; decision-making; accident analysis; signal perception; gap acceptance; task taxonomy; intersections
Related Work: HumRRO Task Analysis; FHWA driving maneuvers research.
Cost: $1 million
Implementation: Apply model to analyze existing and proposed intersections to evaluate safety and efficiency.

INTERSECTIONAL ACCIDENTS -- 6

Title: Methodologies for Studying Multiple-Driver Interaction
Problem: Very little is known about multiple-driver interactions on open highways or in urban settings. Methodologies must be developed to study their interaction. Potential methodologies may include on-road observation and use of probe vehicles; linked interactive simulator facilities; or other laboratory procedures.
Objective: Develop a methodology for studying driver interaction with other road users at intersections. Define procedures that minimize safety and liability problems.
Key Words: Driver behavior; research methodology
Related Work: Army SIMNET; traffic engineering observations; air-to-air combat simulation; Navy submarine vs. submarine encounters; virtual reality systems
Cost: $500,000
Implementation: Provide recommendations for further in-depth testing of promising approaches.

INTERSECTIONAL ACCIDENTS -- 7

Title: Reduction of Left-Turn Accidents
Problem: Left turns interrupt traffic flow and represent a high-conflict maneuver. Left-turn accidents are frequently high-momentum collisions and are accompanied by severe injury and fatalities on many occasions. The configuration of the roadway, the actions of other road users, and the decisions and responses of the driver all contribute to such fatalities.
Objective: Develop an understanding of the relative contribution of roadway characteristics, driver behavior, and highway driver interaction to left-turn accidents. Current information indicates that this accident condition can be improved by engineering manipulations to roadways which subsequently affect drivers' perceptions and actions. Countermeasures should address both driver behavior and intersection operations.
Key Words: Roadway design; driver perception; left-turns
Related Work: FHWA and NCHRP intersection projects; recent research on driver workload; Indiana Tri-level MDAI study.
Cost: $1.75 million
Implementation: Develop positive design guidelines for traffic engineering implementation to reduce left-turn accidents.

Intersectional Accidents -- Additional Problem Titles

Differential Accident Patterns Due to Left-Hand Turns in Rural Vs. Urban Areas

Relative Risk of Driver Strategies Aimed at Avoiding Left-Hand Turns

Crash Criticality by Vehicle Size in Intersections

Geometric Design, Channeling, and Signing Influences on Lane Choices

Effects of Horn Blowing and Tailgating by Other Drivers on Behavior at Intersections

Role of Visual Attention Deficits in Intersection Accidents/Crashes

Need for Advance Information of Cross Street Identification

Role of Visual Field Difficulties in Negotiation of Intersections

Signal Sequencing and Driver Behavior

RUN-OFF-THE-ROAD ACCIDENTS

RUN-OFF-THE-ROAD ACCIDENTS -- 1

Title: Development of Models of Driver Control
Problem: One of the major problems involved in doing run-off-the-road research (and human factors highway safety research in general) is the lack of adequate driver models that take into account such important factors as perception, psychomotor control, cognition, decision-making, and risk perception. Important questions include, (1) What kind of information is the driver using to stay on the roadway? (2) How is he/she using this information? (3) How does he/she translate the available information into decision/control responses, etc.? (4) How do we measure sensitive parametric changes? To address these and other questions, models must be developed in three major areas: (1) perceptual and psychomotor factors; (2) cognitive and central processing factors; and (3) decision-making and the perception of risk. All three of these areas are interrelated, of course, but research aimed at developing useful models in each area should be carried out separately because the relatively high cost of such work.
Objective: Base driver performance predictions and interventions empirically derived models. The need for and use of integrated models that have been carefully derived from real-world data and laboratory research are basic and crucial for such purposes.
Key Words: Driver control; models; psychomotor performance; cognition; decision-making; perception
Related Work: U.S. and European driver modeling work, relevant military operator performance modeling.
Cost: Data acquisition and modeling development by model area:

(1) Perceptual and psychomotor factors	$333,000
(2) Cognitive and central processing factors	$333,000
(3) Decision-making and perception of risk	$333,000

Implementation: After validation, use models in applied human factors and engineering safety research.

RUN-OFF-THE-ROAD ACCIDENTS -- 2

Title: Development of Methodology for Model Validation
Problem: One of the major problems involved in validating driver behavior models centers around the need to obtain unbiased system behavior from drivers. At present, there is no methodology to ensure that methods used in such work are not biased. There is a need to develop data collection that does not influence or bias the data set.
Objective: Develop unbiased validation methods and procedures for measuring driver behavior.
Key Words: Performance estimates; driver behavior; validation methods
Related Work: Trap car techniques; nonobtrusive measurement techniques.
Cost: $100,000; 2 years
Implementation: Use methodologies to appropriately validate driver control models.

RUN-OFF-THE-ROAD ACCIDENTS -- 3

Title: Validation of Driver Control Models
Problem: To be of value, models for use in predicting driver control, doing human factors research, and performing engineering and/or other safety interventions must be empirically validated using real-world data. In the case of models of perceptual and psychomotor performance, for example, it is important that driver behaviors be predicted on actual roadway facilities and under real-world conditions.
Objective: Validate the driver control models. A bilevel approach is suggested in which the model is used to predict driver performance on a wide variety of roadways and in field studies conducted so that real-world driver performance is compared with performance as predicted by the model.
Key Words: Driver control models; validation;decision-making
Related Work: Military experience in model validation; validation of other driver-control models.

Cost: Validation by model area:

(1) Perceptual and psychomotor factors	$1.5 million
(2) Cognitive and central processing factors	$1.5 million
(3) Decision-making and perception of risk	$1.5 million

Implementation: Use models in applied human factors and engineering safety research.

RUN-OFF-THE-ROAD ACCIDENTS -- 4

Title: Technology Transfer of Driver Performance Model
Problem: A driver performance model that is not accessible to researchers and engineers for purposes of driver performance prediction and behavioral or engineering interventions and design is of little value. There is a need, therefore, to develop the means by which information contained in the models can rapidly and effectively be disseminated to those who need it. In doing this, it is important to use interactive graphics technology.
Objective: Study and develop a means by which a driver performance model can be effectively used. A major aim would be to integrate the driver performance model with highway design models.
Key Words: Models; technology transfer; usability
Related Work: Experience with hypertext; military experience with model utilization; the Interactive Highway Design Model

Cost:		
	Start-up costs	$400,000-$500,000
	Subsequent years	$200,000 per year

Implementation: Make the driver performance model available to and usable by the highway design community.

RUN-OFF-THE-ROAD ACCIDENTS -- 5

Title: Development of a Taxonomy of Driver Errors
Problem: There is at present no useful taxonomy of driver errors. At best, we must rely on classifications that have been developed for other purposes, and while there is a certain face validity in using such schemes, there is still a need for categories that address the special needs and purposes of the driving task per se. An adequate taxonomy is a necessary prerequisite for the development of databases for critical incidents in highway accidents.
Objective: Develop a comprehensive taxonomy of human errors while driving. Such a taxonomy (or perhaps series of taxonomies) would be useful in defining parameters for driver control used in any of the models.
Key Words: Driver errors; taxonomy; critical incident analysis, accident analysis
Related Work: NTSB accident investigations; NHTSA ASAP studies; aircraft accident and incident investigations; NRC human error studies; conflict studies; European human error work.
Cost: $150,000; 3 years
Implementation: Improve coding of accident data, provide a framework for critical incident databases, and assist in defining parameters for driver performance models.

RUN-OFF-THE-ROAD ACCIDENTS -- 6

Title: Enhanced Accident Investigation Techniques
Problem: One of the major problems confronting the human factors safety community is the lack of information regarding the initiating and contributing causes and events that lead up to accidents.
Objective: Build a database of initiating causes and events that would allow an in-depth analysis and study of critical incidents. Use "black boxes", surveillance cameras, expert observers, debriefings, focus groups, and improvement of present accident reports.
Key Words: Critical incidents; database; initiating causes/events
Related Work: NTSB accident investigations; ASAP studies; aircraft accident and incident investigations; NRC accident and incident studies; Conflict Studies
Cost: unknown
Implementation: Improve knowledge of initiating causes and contributions leading to accidents, which would greatly enhance highway safety research and interventions at all levels of entry.

HEAD-ON COLLISIONS

HEAD-ON COLLISIONS -- 1

Title: Review and Evaluation of Existing Countermeasures for Head-on Collisions
Problem: Head-on collisions are extremely costly in terms of lives lost as well as severity of injury. These crashes involve passing vehicles on rural, two-lane

roadways, left-turning vehicles on common left-turn lanes, wrong-way turns at intersections and interchanges, as well as a wide variety of other rural and urban situations. State and local agencies have tried a number of different treatments or countermeasures to reduce the frequency and severity of these accidents. These treatments include, but are not limited to, daytime vehicle running lights, raised pavement markers, third lane for passing, signing, and wide center lines. The nature of these countermeasures and their effectiveness need to be determined.

Objective: Determine the effectiveness of currently used treatments to reduce the frequency and severity of head-on collisions. The following research needs to be conducted to achieve the project objective:

- Conduct a large scale survey of state and local law enforcement and highway engineering agencies with a sensitivity to liability issues;
- Identify countermeasures/treatments, both successful and unsuccessful, that have been implemented as a function of geometric and operational conditions;
- Identify evaluations/accident data available on the treatments implemented;
- Assess adequacy of existing data;
- Determine need for new or additional data--both accident data and behavioral data should be considered;
- Specify need for additional research; and
- Complete evaluation of countermeasures/treatments based on available data.

Key Words: Head-on collisions; countermeasures; perception of hazard; risk taking; sign comprehension; decision aids

Related Work: None

Cost: $200,000 - $250,000

Implementation: Produce guidelines that identify effective countermeasures to reduce head-on collisions.

HEAD-ON COLLISIONS -- 2

Title: Retrospective Identification of Behavioral Antecedents to Head-on Collisions

Problem: It is difficult to make progress in the reduction of head-on collision accidents without a better understanding of the behavioral antecedents. It is hypothesized that these antecedents can be categorized. Potential antecedents are risk-taking, visual obscuration, misperception of closing speed and distance, misperception of signing and delineation, misjudgment of vehicle response, etc.

Objectives: Gather, categorize, and characterize the behavioral causes of head-on accidents and near misses by specified driver groups (with different capabilities) in specific traffic situations using an interview technique such as the critical incident analysis. Summarize this information so it can be used to develop countermeasures to reduce head-on collisions. The first phase will involve developing an appropriate protocol for data-gathering using the critical incident technique and appropriate modifications. Issues will include sample selection, selection of interviewers, and interviewing methods. The second phase involves data-gathering using a large nationally representative sample of drivers and locations. The third phase involves analysis by subject matter experts to determine the causes of the individual incidents and to determine frequently recurring patterns.

Key Words: Head-on collisions; behavioral error taxonomies; critical incident techniques

Related Work: Cognitive error models; critical incident techniques; risk-taking behavior; expectancy and misperception; visibility of delineation; oncoming vehicles; comprehension of signs and delineation

Cost: $500,000 over a 3 year period

Implementation: Identify countermeasures that reduce the frequency of pre-head-on-collision behaviors.

HEAD-ON COLLISIONS -- 3

Title: Analysis of Accident-precipitating Driver Information Processing and Response Factors in Head-on Collisions

Problem: Little is known about the relative extent to which target detection, perception, and risk assessment factors (e.g., speed and distance estimation), or decision (risk acceptance) criteria, affect the likelihood of head-on collisions in passing situations. Meaningful measures of the influence of these variables on accident development depend upon realistic stimulus presentation in believable conflict situations. Assumptions in this research are that (1) a following driver wishes to pass a lead vehicle on a 2-lane highway, and (2) avoidance of a head-on collision depends upon timely and accurate processing of all pertinent vehicle, highway, and situational information. Analysis of driver information processing and response factors influencing occurrences of this accident type will focus on the yes/no decision to initiate a pass under designated operational conditions and will include individuals representing a range of perceptual/cognitive capability and risk acceptance criteria.

Objective: Define human performance characteristics in controlled laboratory and field studies of real-time decision-making. A preliminary requirement is to field validate a generalizable methodology. The adequacy of existing geometric standards to accommodate human requirements necessary to avoid head-on collisons will be investigated.
Key Words: Passing; overtaking; driver performance; risk-taking; traffic operations; highway geometry; pavement markings
Related Work: FHWA Large Trucks Study; risk perception/risk homeostasis work; OECD-sponsored overtaking studies; FHWA maneuvers research.
Cost: $400,000 - $500,000
Implementation: Produce handbooks, driver performance models, and/or databases aimed at the development of improved standards for the reduction of head-on accidents.

HEAD-ON COLLISIONS -- 4

Title: Develop Countermeasures to Aid Driver Information Processing in Passing Situations Under Opposing Traffic
Problem: Pass/no pass decisions are difficult. It is currently unclear what information drivers use in order to make these decisions. Many technology options are available to help in the process. There is a need to delineate the decision-making process, including decision-making at different levels of uncertainty. Drivers apparently rely on incomplete information about the relative velocities and available distances. Following this, the driver's decision-making process needs to be modelled to include perceptual time, reaction time, and clarification of the informational elements to assess their contribution to drivers' decisions.
Objective: Develop decision-making aids that will simplify decision making for drivers and assess which types of information and countermeasures are most effective for particular situations and/or circumstances. Several different types of decision aids will be investigated, including roadside information, signage, predictive aids inside the vehicle, and communication aids between the oncoming and the lead vehicle. It is anticipated that initial work will involve a comprehensive literature search to isolate the salient variables followed by simulator-based research for comparative evaluation of the different types of driver decision aids, which will take place in a high-resolution simulator. Field validation research will follow this project.
Key Words: Head-on collisions; driver perception of risk; driver decision-making; passing zones
Related Work: Driver variability and perception of risk; FHWA maneuvers research; work on closure rate and special estimates.
Cost: $500,000 over 3 years
Implementation: Develop countermeasures to reduce the incidence and severity of head-on collisions. The project will also aid in the development of IVHS technology by assessing the types of information driver need and which information types should be considered for inclusion in this technology.

Head-On Collisions -- Additional Problem Titles

Avoidance Decision Options

Factors Involved in Drivers' Choice of Lane Position

CROSS-CUTTING ISSUES

CROSS-CUTTING ISSUES -- 1

Title: Factors Affecting Driver Response Times to Roadway Hazards
Problem: The response time of drivers to the detection of hazardous obstacles in the roadway ahead should be a key element in accident investigation, driver education, and highway design. However, the overall time required for an effective response (steering, braking, accelerating) is a function of many variables whose effects have not been systematically studied. For example, the rule-of-thumb stopping distance for the driver of a heavy commercial vehicle is based on hazard perception time (750 ms), plus reaction time (750 ms), plus braking distance (e.g., 4.5 seconds at 55 mph) (Wylie and Shultz, 1989). The origin of this formulation is lost in obscurity; it is only certain that it does not apply to all truck drivers under all circumstances, but probably reflects a minimum total response time.

Objective information concerning the effect of numerous relevant variables on driver response time is required and should be compared with a meaningful baseline, such as the response time of young drivers, fully alert, under ideal driving conditions. Total response time is conceived of as including perception time (a potential hazard lies ahead) interpretation time (what is it, is it stationary or moving, will it intersect my track?), decision time (whether to brake, steer, accelerate, or some combination of these), and execution time (including for heavy vehicles the response time of the airbrake system).

It is hypothesized that total response time varies as a function of at least the following factors, each of which is expected to increase response time in relation to baseline:

- driver age
- circadian changes in alertness
- traffic conditions
- drugs (legal, illegal)
- highway monotony
- driver fatigue
- level of roadway illumination
- weather conditions
- alcohol

Furthermore, several of these variables may interact as critical precursors of accidents.

Objective: Generate objective baseline response time data and data reflecting the impact of the variables listed above, as well as meaningful combinations of those variables on overall driver response time to various roadway hazards. The result should be response time data base ranging from baseline to worst-case conditions.

Consideration should be given to the generation of such data bases for both passenger cars and heavy motor vehicles. The latter, for example, include additional components of response time associated with the braking system and alignment of the brakes in both tractor and trailer. Linear, serial models of driver response should not be exclusively considered in this work.

While it may be tempting to perform some of the required research in a driving simulator, there may be major problems in establishing the correct transfer function to real world driving conditions. Since performing the research in an operational driving environment is impractical for reasons of safety, the best choice appears to be a closed-track environment having characteristics that make possible the investigation of most, or all, of the independent variables listed in the foregoing problem statement.

Key Words: Driver response time; perception time; decision-making time; hazard perception; factors affecting response time

Related Work: FHWA perception-reaction time research.

Cost: $300,000 - $500,000 depending on whether both passenger and commercial vehicles are included

Implementation: Develop the described data base which should have long-term usefulness for establishing the driver's role in accident causation and the exacerbating effects of variables that significantly and adversely affect driver response time. This information should be of value to driver training programs, driver licensing requirements, and traffic engineers.

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CROSS-CUTTING ISSUES -- 2

Title: Driver Fatigue and Associated Loss of Alertness in Automobile Accidents

Problem: A substantial proportion of all accidents, particularly run-off-the-road accidents, appears to be attributable to loss of alertness associated with driver fatigue. These accidents are often characterized by the fact that the driver made either a much delayed emergency response to an impending hazard or no response at all. In accidents involving heavy commercial vehicles, driver fatigue has been identified as the most frequent cause of fatal-to-the-driver accidents (National Transportation Safety Board, 1990). A comprehensive field study of this problem in truck drivers is currently under way, but the extent of the problem in automobile and light truck driving is unknown. It is likely to be extensive, however, since many of the same variables that are responsible for loss of alertness in truck and bus drivers appear to operate regardless of vehicle type. The extent of this problem in automobile drivers needs to be documented, and potential countermeasures need to be identified and evaluated.

Objective: Using existing accident data as a starting place, determine the extent of the automobile driver fatigue/loss of alertness problem. The accident subset involving run-off-the-road accidents is one subset of obvious importance, although there may be others. The probable role of driver fatigue and associated factors should then be determined through interviews with survivors of such accidents. Associated factors would include time of day at which the accident occurred; how long the driver had been driving at the time of the accident; how long the driver had been continuously awake at the time of the accident (including the possibility of sleep debt); the type of highway involved and traffic density (conditions leading to boredom); probable circadian effects on driver's state of alertness; etc. Combinations of these factors (e.g., experiencing a circadian nadir in conjunction with sleep debt and long, tedious driving conditions) should be evaluated, as should individual differences in susceptibility to such influences. For example, susceptibility may be related to driver age, sleep disorders, and other factors. Potential countermeasures to the problem of driver fatigue should be identified and evaluated for their potential usefulness. Experimental evaluation may be required, but this is not a part of this proposal.

All relevant literature should be carefully evaluated. Existing accident data bases should be examined for their usefulness. Although a useful starting point, they are likely to be deficient in critical information related to driver fatigue. Interviews with accident victims must be skillfully formulated and carried out with all necessary considerations of privacy.

Key Words: Driver fatigue; loss of alertness; driver drowsiness; countermeasures

Related Work: Fatigue in truck driver;driver impairment in driving simulators; sleep deprivation studies; countermeasures of driver fatigue. All of this work presumes a relationship between driver fatigue/loss of alertness and accidents. None, however, clearly documents this relationship or its likely pervasiveness in automobile driving.

Cost: $250,000 - $300,000

Implementation: Having documented the role (frequency, causes, effects) of fatigue in automobile and light truck accidents, formulate a variety of countermeasures to the problem, some of which may require experimental validation. Objective information concerning the extent of the driver fatigue problem will be generated, and factors that exacerbate the problem will be identified. This will be directly useful in public information campaigns, driver training courses, and driver licensing programs.

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Additional Problem Titles

Factors That Differentiate Near Misses From Collisions

Perception of Risk and the Failure to Obey Traffic Control Devices

Driver Adaptation Effects to Changes in TCDs and Geometric Designs

Effects of Automatic (Habitual) Driving Control on Time-Pressured Decisions

Instructional Needs About Traffic Control Devices

Roadway Lighting and the Older Driver

Role of Simulation Research in Imminent Collision Situations

Effects of Environmental Changes on Driver Scanning Behavior

The Need For Critical Incident Studies of Pre-Near Misses

Factors Affecting Speed Choices On Low Coefficient Surfaces

Instructional Needs With Regard to Improved Implementation of Improved Standards

Effects of Sign Proliferation and Nonstandardization

Human Factors Considerations in Anti-Collision Devices

Effects of Sustained High Speed and Darkness on Driver Performance

Unobtrusive Measures of Driver Behavior

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