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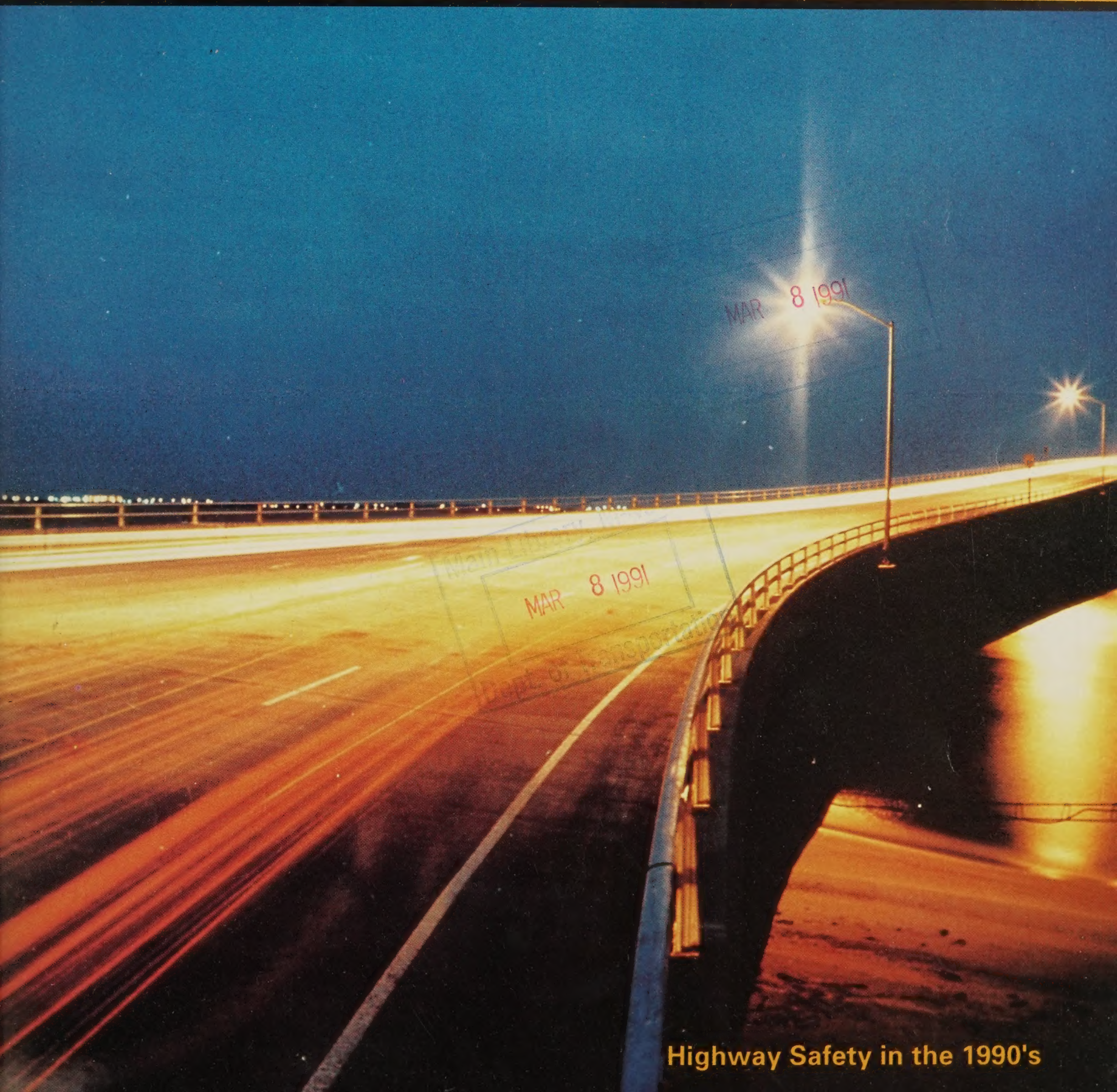

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Highway Safety in the Nineties

by Samuel C. Tignor, Ph.D., P.E.

Introduction

Recent safety campaigns on the use of seat belts and on drinking and driving show the public cares about safety and demands action. During the 1990's, the public will probably continue to promote other highway safety initiatives to reduce the annual societal loss due to highway transportation fatalities and injuries; this loss is currently estimated at about $95 billion per year. We are thus entering a period in which the public will demand and expect significant improvements in highway safety. This article highlights key ongoing or projected safety initiatives.

Past and Current Trends in Highway Safety

During the past 40 years numerous highway safety improvements have been made. Probably the most significant of these was the building of the Interstate system of highways, which began in 1957. Another milestone was the Highway Safety Act of 1966 which created a set of 18 standards addressing such issues as highway geometrics, traffic engineering, vehicle standards and safety, driver licensing and education, pedestrian safety, and accident investigation. In addition, many physical safety improvements were introduced in the sixties and seventies involving roadside environment; these included:

- Development and use of breakaway sign supports to replace earlier noncollapsible supports.
- Improvement of narrow median safety by using various guardrail, cable, and chain link systems. (The concrete median barrier with special end treatments has proved to be particularly useful on heavily traveled freeways.)
- Development and implementation of various crash attenuators for application in gore areas, on the back of maintenance vehicles, etc.
- Removal of protruding above-ground surfaces such as drainage headwalls, steep ditches and slopes, and abrupt guardrail ends.

A final highway safety area in which numerous recent improvements have been made is that of traffic control. Specific improvements include:

- Use of microcomputer systems rather than electromechanical controllers to monitor traffic flows and manage the traffic signals in complex urban networks and arterial traffic control systems.
- Enhancement of freeway traffic management system technology. Currently seven such systems are helping to relieve congestion, especially during incidents, in urban areas like Los Angeles, Chicago, Minneapolis, Seattle, Long Island, Detroit, and Northern Virginia.
- Introduction and enhancement of delineation devices to enable drivers to find the roadway even under dark, rainy conditions. Devices include new retroreflective materials, raised pavement markers, and improved signage and pavement markings.
- Better work zone and incident management through use of such electronic warning systems as arrow boards, changeable message signs, and roadside radio.
- Use of lighter, more visible traffic control devices in work zones, replacing large timber barricades that were more lethal than forgiving.
- Development of open-graded asphalt paving and grooved concrete pavements to provide better drainage and prevent hydroplaning in wet weather.

Safety Trends for the Nineties

The highway fatality rate in the United States is 60 percent less than it was in 1957. However, by the year 2000, the projected number of highway fatalities will be 65,000 if the current fatality rate of 2.2 per 100 million vehicle miles (MVM) is not reduced.
In economic terms, given today's dollar value, this rate of fatalities represents a loss of over $130 billion each year. This current fatality rate and number of fatalities are much too high; the challenge is to reduce each of these statistics significantly. Some have suggested that the fatality rate be reduced to 1.5 per 100 MVM by the year 2000.

The challenge is not an easy one. The U.S. highway system consists of a massive 3.8 million miles of roads. Further, the randomness of highway accidents magnifies the difficulty of lowering fatality statistics.

Despite this randomness, however, some observations can be made regarding general trends in highway fatalities (table 1). First, the number of rural fatalities is disproportionately greater than the amount of rural travel, suggesting that additional safety emphasis should be placed on rural highways. Second, the proportion of pedestrian fatalities in urban areas is nearly 10 times than that found in rural areas, signifying that more should be done to protect urban pedestrians. Third, for both rural and urban areas, the percentage of fatalities occurring at night is about twice the amount of night travel, indicating that improvements should be made to ensure that the driving environment is safer for night travel.

Table 1.—Some highway fatality statistics

Situation	Percentage of all fatalities	Travel
All rural vs. total	56	40
All Interstate vs. total	10	22
Pedestrian vs. all other	17	
Rural		
Nighttime	55	25
Pedestrian vs. nonpedestrian	6	
Urban		
Nighttime	57	25
Pedestrian vs. nonpedestrian	37	
Pedestrian vs. total pedestrian	76	

Predictions

The 1990's will likely see a continued and enhanced interest by the public in demanding improved highway safety. The highly successful results of drunk driving and seat belt legislation and public use campaigns testify to the public interest in improving highway safety.

It is hard to predict what other areas may receive similar acceptance. These are, however, various areas in which existing and soon-to-exist technology can help to increase highway safety and reduce the total number of highway fatalities and injuries.

Roadside

Twenty-seven percent of all highway fatalities occur on the roadside. To reduce this rate, roadside safety hardware should not contribute to highway injuries. For example, improved guardrail systems should be developed; utility poles should be set further from the travel way; and roadside slopes and ditches should be flattened.

Night visibility enhancements

Drivers need improved delineation and signing of the roadway. Much greater use should be made of pavement markers—probably recessed—and wider edgelines. Longer lasting pavement marking materials would also be useful. Retroreflective signing materials should be used more frequently, especially where there is a lot of roadside advertising or other sources of competing light.

A disproportionate number of nighttime fatalities are occurring. Because the *1989 Annual Report on Highway Safety Improvement Programs* showed roadway lighting as second in a list of 20 highway safety improvements with the highest benefit-cost ratio, greater use of highway lighting is likely to occur during the 1990's, especially on heavily traveled facilities.

New proposed National Highway Traffic Safety Administration (NHTSA) automotive headlight system standards should assure nighttime visibility of retroreflective signs by providing for minimum luminous intensities above the horizontal. However, caution must be taken relative to possible color changes induced by new headlamp light sources. Based upon a completed Federal Highway Administration (FHWA) study, it has been found that some slight color shifts may occur, primarily in the red signs. Proposed changes in automotive headlamp light sources must prevent color changes—particularly with reds, oranges, and yellows—in highway signing thereby causing potential confusion to drivers in recognizing regulatory and warning signs.

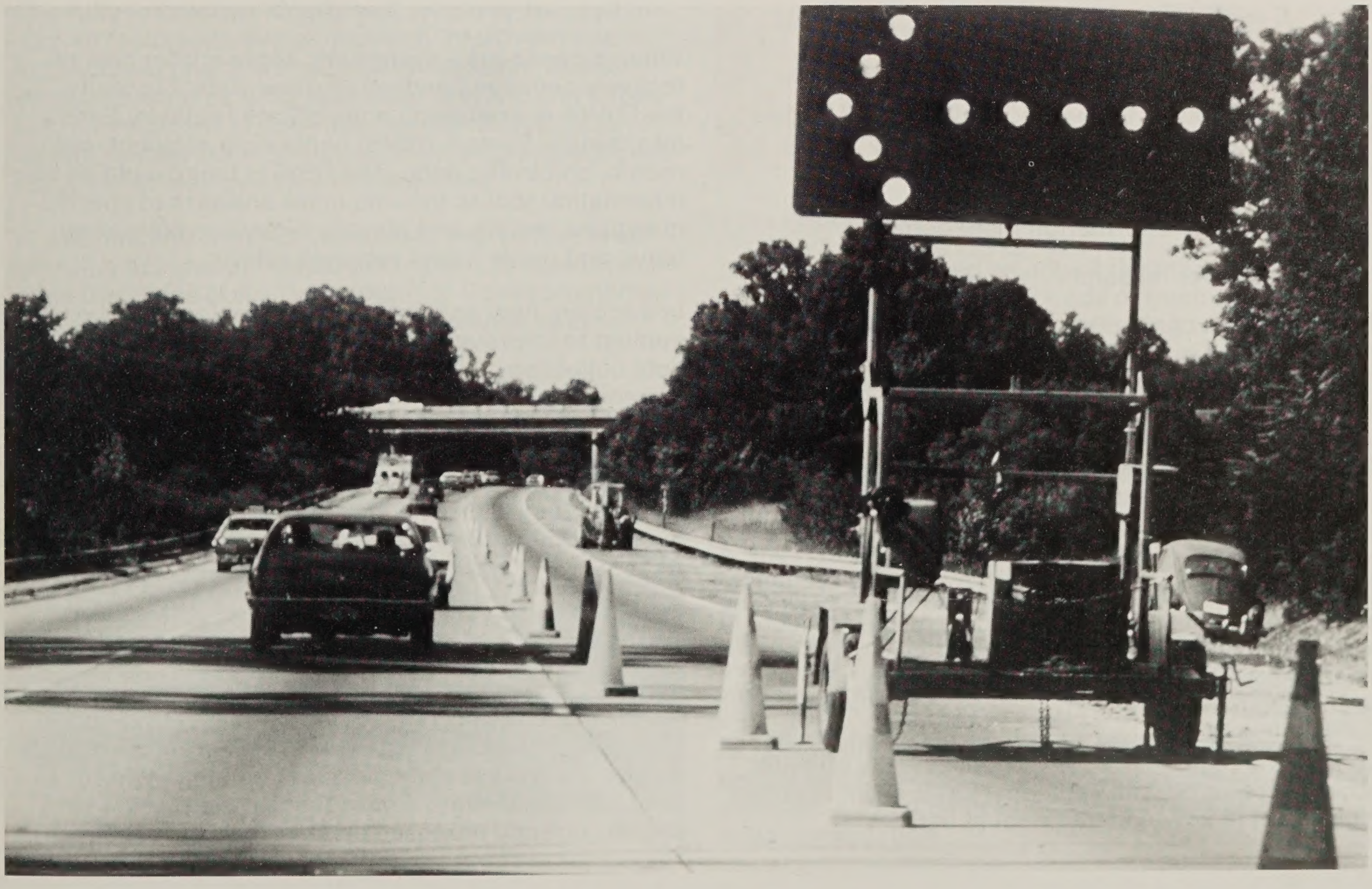
Work zones

Work zone fatalities increased more than 40 percent during the first half of the 1980's; 30 percent of such fatalities occur on the Interstate system. This death toll, now 700 per year, will continue to increase unless highway engineers become increasingly vigilant in applying good traffic management and control systems in work zones. The increase in work zone construction projected for the 1990's will demand a continued strong and concentrated effort in providing good delineation and warning of work zone hazards to the public.

Enhanced traffic control and engineering demands

The highway industry currently has tools and systems available for microcomputer traffic control, traffic surveillance and management, automated vehicle identification, and roadside communication. Although this technology is available, its application has been limited by funding constraints and a scarcity of qualified technicians. Greatly expanded use of this technology will be required to meet the economic demands of the traveling public in the 1990's.

The major thrust in this area will probably be in terms of traffic management. The public will demand much greater responsiveness to and alleviation of major traffic incidents by police and departments of transportation. Far too many routine incidents have resulted in hours of delay to thousands of motorists because of no communication, no route diversion, and inadequate emergency equipment. Traffic engineers should have a greater responsibility in developing solutions to these problems, but will require more funds to do so.



FHWA Safety Program for the 1990's

The FHWA Office of Research and Development has identified high-priority safety areas for the 1990's, including:

- Highway safety information management.
- Driver behavior research.
- Development of an enhanced highway simulator.
- Highway design management.
- Improvement of pedestrian safety.
- Development of improved traffic control methods.

Highway Safety Information Management

Currently, neither the FHWA nor the States have economical and timely access to the data needed to identify highway safety problems, effectively direct highway safety research, develop sound safety policy, and accurately determine the effectiveness of safety programs. On the other hand, however, States and local jurisdictions spend more than $500 million annually on traffic accident reporting with additional funds spent to collect highway inventory and traffic count data.

What is needed is a systematic approach for cost effectively collecting and using these data. Currently, the FHWA is evaluating a multiState Highway Safety Information System (HSIS) containing accident, geometric, and traffic data. The HSIS is being used as an information tool to provide quick answers to specific questions, isolate and identify highway safety problems, and guide future research efforts.

In addition, new and emerging technology will be applied to improve the quality and economics of field data collection. Such technology includes the use of geographic information systems for combining accident, geometric, and traffic data; the development of portable computerized data input devices to improve the speed and accuracy of accident reporting; and the integration of videodisc photologs for collecting roadway information.

Driver Behavior Research

When the roadway design fails to account adequately for driver limitations and capabilities, accidents are often the tragic result. For example, many of the accidents cited as due to "improper driver lookout" actually involve inadequate sight distance and other aspects of poor highway design. Consequently, most of the research currently proposed on driver behavior is aimed at identifying and understanding situations in which there is a mismatch between driver capabilities and highway design. Once the mismatch is understood, development efforts can begin to correct these problems with practical and cost-effective countermeasures.

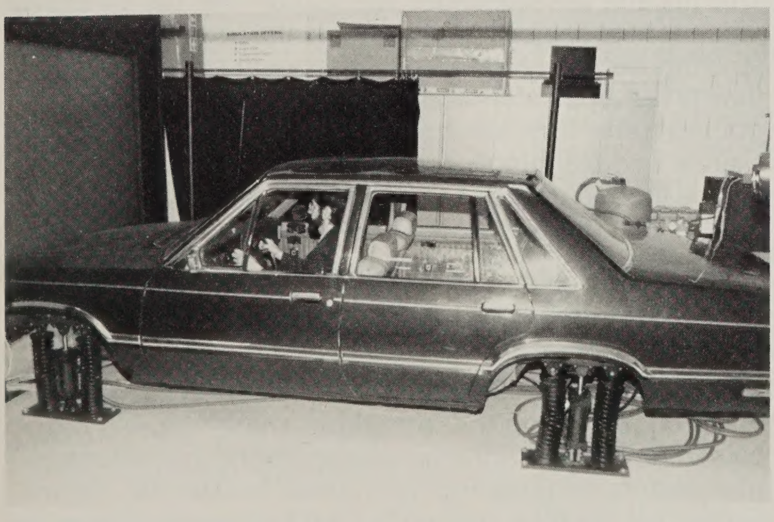
Specifically, the FHWA driver behavior research program addresses age specific driver problems, driver fatigue, accident evasion skills, behavior adaptation, adverse weather and reduced visibility problems, attention and alertness, information overload, driver expectancy, perception of maneuver response time, and public education. Recently developed highway simulation technology (described below) will enable investigation of driver behavior issues that have previously been impossible to address, concerning the driver behavior aspects of highway safety.

Enhanced Highway Simulator

The early generation simulator now being used at the FHWA's Turner-Fairbank Highway Research Center will be enhanced to meet the next 5 years of driver behavior and vehicle dynamics research and development needs. The highway simulator (HYSIM) will feature quality graphic presentations of dynamic traffic scenes including complex roadway geometry, traffic control devices, fixed objects, and interactive traffic. The system will also provide limited motion to simulate roadway surface/engine-drivetrain vibrations, roll, pitch, yaw, and heave motions.

The fully interactive HYSIM will primarily be used in human factors studies concerning improvements in highway signing and roadway delineation, assessment of problems unique to older drivers, and subsequent evaluation of potential countermeasures, and design optimization of human interfaces in intelligent vehicle-highway systems development.

In addition, the FHWA is supporting the NHTSA in obtaining a national advanced driving simulator which can meet the needs of the Department of Transportation as well as those in universities and the private sector.



Highway Design Management

Highway design management research in the 1990's will attempt to determine the relationship between accidents and highway design and operational features. As shown in table 2, fatalities seem to result from a relatively small number of highway situations.

Table 2.—Highway fatalities

Situation	1988 Fatalities
Total fatalities	47,093
Single vehicle fatalities	26,333
Fatalities with fixed objects	12,674
Collisions with guardrail	1,229
Collisions with trees	3,293
Collisions with utility poles	2,480
Rollovers	4,989
Multi-vehicle	20,760
Head-on collisions	7,791
At intersections/interchanges	
Rural	3,651
Urban	5,815

The HSIS will be used as one of the major sources of information to identify the kinds of geometric and traffic characteristics that are contributing to accident and fatality problems. Highway accidents will be analyzed to determine if their causes relate to vehicle maneuvers, driver error, and/or roadway design characteristics. The economics of highway safety improvements will be determined relative to the costs and effects of proposed highway design changes.

A major emphasis will be placed on developing a quantified procedure for assessing or rating the safety level of sections of highway. The procedure will take into account the ability of the highway, as defined by its specific geometric elements, to service individual unconstrained vehicles, as well as the population of vehicles expected to use the highway during its design life. When developed, the procedure will permit better decision making concerning what safety elements should be designed into a roadway prior to its construction.

Pedestrian Safety

Pedestrian safety is a joint responsibility of the FHWA and the NHTSA. To reduce pedestrian fatalities and injuries, the two agencies will coordinate a program emphasizing the development of public information and training opportunities describing pedestrian hazards and safety precautions.

The program will entail systematic use of accident data and employment of human factors principles. Pedestrian accidents will be reviewed so as to classify them into commonly occurring "accident types." Pedestrian hazard exposure also will be investigated to determine situations in which pedestrians are most vulnerable. Accident countermeasures will be developed for the most commonly occurring pedestrian accident types; accidents and their costs will be widely publicized and cost-effective countermeasures promoted. Pedestrian training needs will be identified and training programs implemented.

Finally, procedures will be developed so that pedestrian safety and operational needs will be incorporated into normal land use planning and highway planning and design processes.

Improved Traffic Control Methods

Warning and control information on today's highways is provided through a system of signs, signals, and markings known as traffic control devices. Most of these signs and markings are "static" (i.e., their messages never change). Research has found that drivers violate traffic controls when they think the devices are inappropriate, not credible, or defective.

FHWA research during the 1990's will be undertaken to provide real-time safety advisory and warnings through roadside and in-vehicle devices. These traffic control methods and devices will provide useful, up-to-date, and meaningful warning and control information depending on roadway, traffic, and environmental conditions measured. Specifically, Intelligent Vehicle-Highway Systems (IVHS) technology is being proposed that can be used by either roadside or in-vehicle receivers. While this development is primarily intended for major arterial type roadways and their intersections, freeway applications are also included.

IVHS technology will enhance highway safety in ways not previously available. For example, faster response times for emergency medical services could be provided by the use of sensors that would automatically detect an accident-involved vehicle and transmit radio signals to a command center giving the exact location and time of the accident. This application would be especially useful in remote rural areas where reduction in average response time could save an estimated 700 lives per year.

Summary

Today's populations of 160 million drivers and 180 million vehicles are sure to increase. What we cannot allow to increase is the number of annual fatalities. If unchecked, these fatalities, which are now at 47,000 could grow to 65,000 by the year 2000, assuming a traffic growth of 4 percent per year and a fatality rate of 2.2 per 100 MVM.

Although numerous highway safety improvements have been made since the 1960's, the safety issue is by no means resolved. Therefore, continued and new highway safety initiatives can—and must—be expected during the 1990's.

To achieve the goal of fewer fatalities and a reduced fatality rate, existing and new technology must be sought and used. New technology is available, but its adaptation to today's highway systems has not kept pace with the increased demand for mobility. We therefore need to increase the rate of implementation for those strategies and techniques that we know will increase safety. Moreover, because the transportation strategies developed 30 to 40 years ago have become inappropriate for today's congestion and travel demands, highway, operational, and roadside safety problems will have to be better identified, and driver needs and limitations better understood.

This decade will see wider application and use of design approaches, devices, and systems that are now available but not widely used. Chief among these will be new IVHS-type safety technology developed for integrating traffic flow information with individual driver decisions and planning. Deployment of this technology will be limited at first, but will increase later in the decade. The net result should be a safer and more mobile cost-effective highway transportation system.

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The Highway Safety Information System: Applications and Future Directions

Jeffrey F. Paniati and Forrest M. Council

This is the second in a two-part series of articles describing the development and use of a new highway safety data base. The first article, published in the December 1990 issue of Public Roads, described the need for such a data base, its design, and its content. This article provides an overview of this newly operating data base, illustrates its potential applications, and outlines future development plans.

Introduction

The Highway Safety Information System (HSIS) is a new highway safety data base developed by the Federal Highway Administration (FHWA) and the University of North Carolina Highway Safety Research Center (HSRC). Safety analysts and highway engineers are using the HSIS to access accident, traffic, and roadway data for a variety of applications, ranging from basic problem identification to modeling efforts that attempt to predict future accidents. Note that the goal of the HSIS is not to provide national accident statistics; rather, the HSIS is designed to provide a detailed system linking accident, roadway, and traffic data for problem analysis.

This article describes the capabilities and characteristics of the HSIS and provides five problem analysis examples that illustrate how the HSIS can be used as a problem solving tool. The article also discusses future enhancements to the system that might significantly improve the range of analyses for which the HSIS can be used.

Background

A location-based accident system, the HSIS combines high-quality accident, roadway, and traffic data in a computer-linkable format. The system uses raw data already collected by a select group of States.

Currently, the HSIS includes 5 years of data (1985-89) from five States: Illinois, Maine, Michigan, Minnesota, Utah. These States were selected based on three primary criteria: the quantity of data collected, the quality of the data, and the demonstrated ability to merge data from different files.

The FHWA acquires these data annually, conducts quality control checks, prepares the data in a standard format (SAS), and downloads the data to a microcomputer. These data can then be merged for use in traffic safety analyses. Given the quality and quantity of HSIS data and the ability of the files to be merged with each other, the HSIS is a powerful, flexible tool for analyzing numerous safety issues. For example, if an analyst is studying driver or roadway factors, the HSIS can be used to determine basic problem identification issues. If the analyst needs to predict the nature and location of future accidents using accident, roadway, traffic variables, the HSIS can be used to construct multivariate models.

Initially designed as a mainframe system in which all activities were conducted on the HSRC and the FHWA mainframe facilities, the HSIS was recently converted to a microcomputer-based system. Thus, it is now more accessible for use in measuring highway safety in terms of accident frequency or rates, and relating those measures to factors such as highway geometric design, traffic control devices, roadside hardware and operating policies.

The following problem analysis examples illustrate the range of analyses that the HSIS can perform. While the issues and scope in each case differ, the first step for conducting the analysis is the same: the analyst must define the critical variables and determine the feasibility of using the data available to address the problem.

1: Sight Distance

A feasibility study using HSIS data for quantifying the accident effects of crest vertical curves was recently completed.

Problem

On rural highways, stopping sight distance—the required distance needed by a vehicle to stop before reaching a stationary object—is often factor-related to safety. Moreover, this distance is used to determine the minimum length of a crest vertical curve. Although, the American Association of State Highway and Transportation Officials' *Policy on Geometric Design of Highways and Streets* provides guidelines on the design of such curves, in recent years, the adequacy of these guidelines has been questioned.

HSIS analysis steps

The critical variables, as defined in this feasibility study, were vertical grade and related stopping sight distance information. A review of the State files found that two of the five HSIS States had grade location data; however, one could not be used because it contained data only for substandard vertical curves. The remaining State had appropriate information for all grades, and from these data, nearly 2,400 crest vertical curves were identified.(*1*)[1]

As expected, the State files did not contain specific roadway data on the stopping sight distance associated with each vertical curve. State inventory files cannot capture all the desired variables related to the roadway.

To compensate for the missing data, the analyst merged the accident data with each vertical curve and determined the distance from each accident to the crest of the curve. A plot of accidents versus these distances was made to gain insight into how accidents cluster with respect to vertical crests.

Figure 1 illustrates the results which are plotted both for curves with a grade differential (upgrade plus downgrade) of less than 6 percent and for those with more than 6 percent. The graph shows that a greater proportion of the accidents are found within .02 mi (32.19 m) of the crest and that increased grade differentials show an even greater proportion of accidents. Because grade differential and length of vertical curve determine the available stopping sight distance, these data indicate a potential problem.

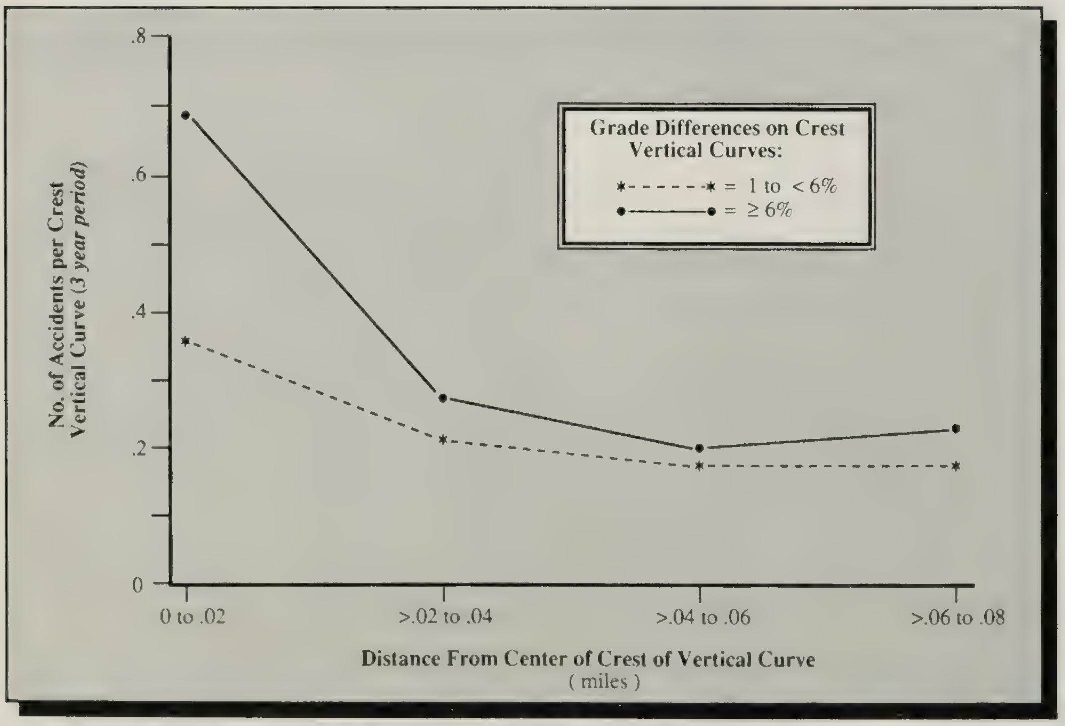

Figure 1.—Accident frequency relative to distance from crest vertical curves.

[1]Italic numbers in parentheses identify references on page 278.

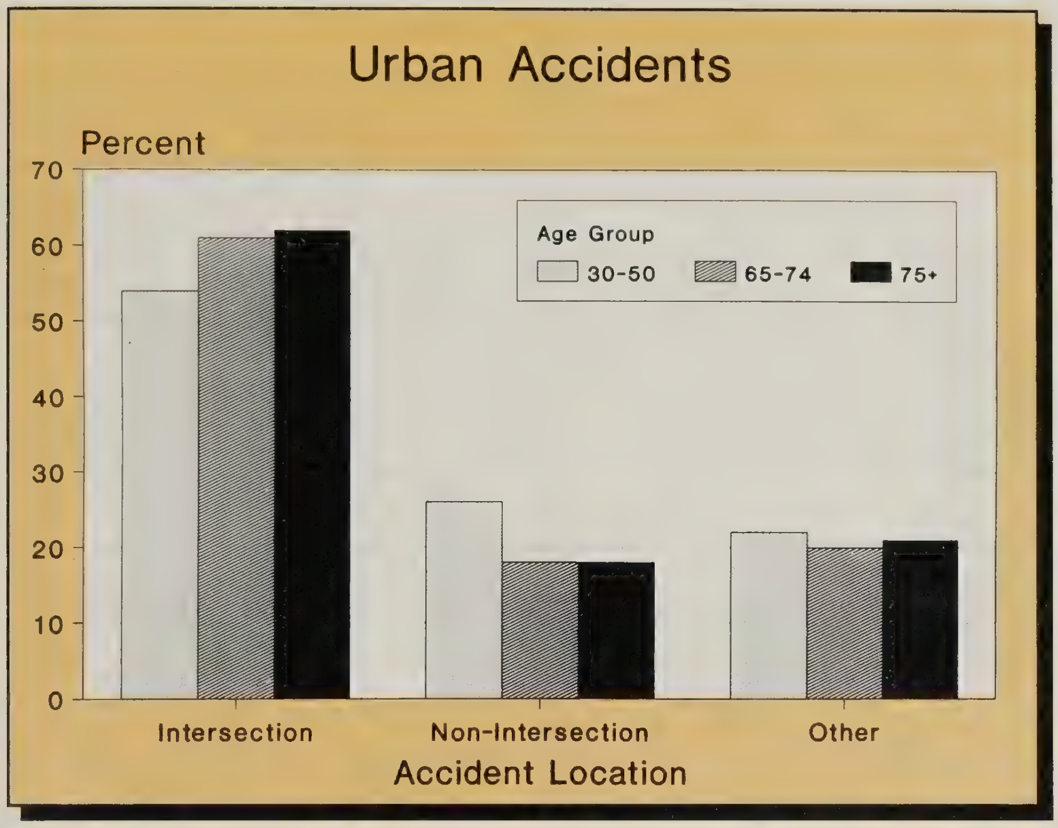

Figure 2.—Location of urban accidents (by age group).

This quick examination of the available data was only part of the feasibility study. The study also recommended other roadway and traffic variables to be examined in more detail and suggested other non-HSIS States that may have useful vertical grade data. Any full analysis will require additional field measures of actual sight distance and vertical curve geometrics to determine the relationship between grade differential and stopping sight distance.

2: The Older Driver

Problem identification represents another type of typical HSIS analysis. Here driver, vehicle, roadway, or traffic characteristics that are thought to contribute to an accident problem are investigated. The findings are then used to direct future research and select appropriate countermeasures.

Problem

Recent research has shown that older drivers, as a group, have significantly higher accident rates than average. This research has major ramifications considering the rapid aging of the U.S. population and projections that older drivers in the next generation will rely even more heavily on automobile mobility than today's older drivers.

The FHWA has developed a research program whose goal is to identify, develop, and evaluate engineering enhancements to the highway system to meet the needs of older drivers. Information on the accident patterns of the older driver is needed to identify the extent of the problem, isolate problem areas, and develop solutions.

HSIS analysis steps

By combining the accident, roadway, and traffic files in the HSIS, analysts can use the data to identify the situations where older drivers are overrepresented. These analyses can be conducted on a State-by-State basis to see if the trends are consistent.

This HSIS study of older drivers is still continuing; however, one State's data has been analyzed. For this State, the accident patterns for both the "young elderly" (ages 65 to 74) and the "old elderly" (ages 75 and older) were compared to those for younger drivers (ages 30 to 50). A wide range of variables was examined and the frequency and proportion of accidents were compared among the three age groups.

Figure 2 illustrates the findings from a comparison of intersection and nonintersection accidents for the three groups. The graph shows that both the elderly groups are involved in a higher proportion of intersection accidents than younger drivers. This was true both for urban and rural locations. Examining the type of intersection accidents where older drivers are overrepresented (figure 3) shows, older drivers are involved in a greater

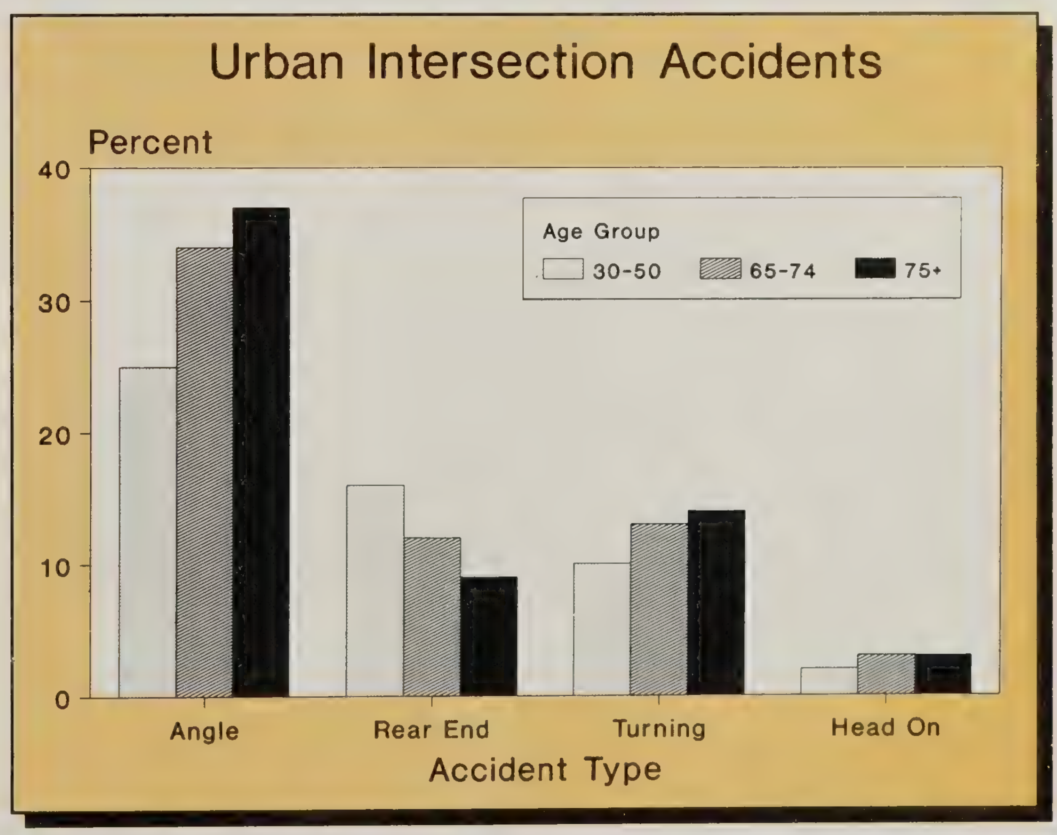

Figure 3.—Urban intersection accident types (by age group).

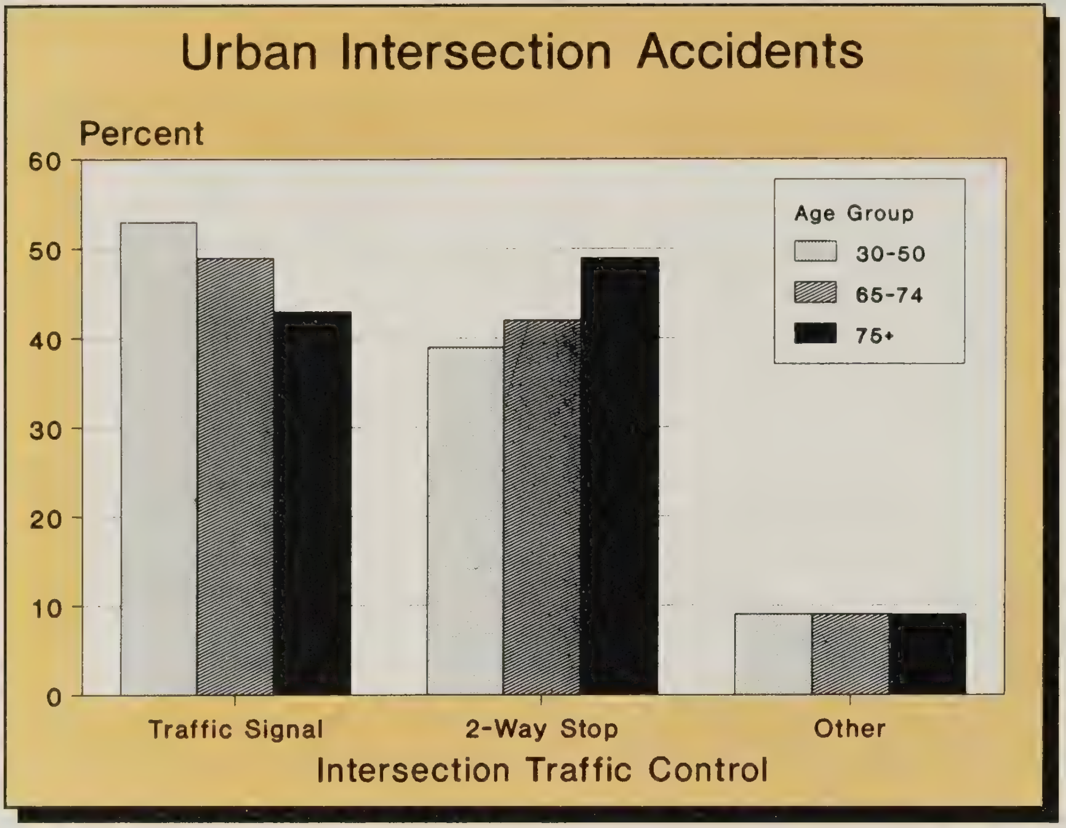

Figure 4.—Effect of traffic control on urban intersection accidents (by age group).

percentage of angle and turning accidents. Further study revealed that the major source of this accident problem was at two-way stop controlled intersections rather than at signalized intersections (See figure 4.)

Clearly, problem identification analysis cannot define the specific risk levels of older drivers, because the HSIS does not classify exposure information by age of driver. Also, overrepresentation at stop-controlled intersections may be partially a result of the fact that more older drivers travel in areas where more stop-controlled intersections are found. However, highway engineers can use this information to gain insight both into locations where accidents involving the elderly occur and into the type of accidents they are involved in.

Given the above data, the engineer, when designing roadway improvements, can focus on those situations where the driver must judge the available gap and the speed of approaching vehicles.

Possible countermeasures may involve treatments such as increasing sight distance or improving intersection control.

3: Median Crossover Accident Rates

The previous analyses focused on problem identification involving accident and roadway information and used accident frequencies (and proportions) to measure highway "unsafety." The following analysis is an example in which accident and roadway information must be merged with traffic data to produce accident rates (accidents per million vehicle miles). Instead of attaching certain roadway variables to each accident, a sample of roadway sections is defined by certain characteristics, and the appropriate accidents and traffic information are extracted for each section. In this way, the HSIS can be used to study a problem by examining how changes in roadway and traffic features affect accident rates.(*2*)

Problem

The increase in travel demand in the United States has resulted in high levels of congestion in many urban and suburban areas. In response to the growing congestion, highway agencies are seeking opportunities to increase the capacity of existing freeways by adding lanes. Because the amount of right-of-way available for this expansion is limited, additional lanes are often constructed by using portions of the existing highway right-of-way, including the median. Reducing the median width, however, has led highway engineers to question the safety of the remaining median width and has forced them to make decisions regarding the use of median barriers.

Specifically, the engineer must trade off the need to minimize the number of median crossover accidents (accidents in which a vehicle from one side of the highway crosses the median and strikes a vehicle in the opposite direction) with a decision to install a median barrier that could result in less recovery area, more fixed object impacts, and more redirected accidents (accidents where a vehicle strikes a barrier and is redirected into the traffic stream). To examine the possible implications of either decision, the engineer must look at information on existing roadways covering a range of median conditions.

HSIS analysis steps

An effort to develop median crossover accident rates was undertaken. This task required the linking of information about the accident type with roadway data (median width and type), with traffic data.

In reviewing the HSIS data files, three of the five HSIS States had the roadway information necessary to conduct this analysis. However, none of these States recorded median crossover accidents as such: instead they grouped these accidents under more general categories—head-on and sideswipe accidents. To estimate the number of median crossover accidents, the analyst looked at the number of head-on and sideswipe opposite direction accidents that occurred on divided roadways. However, analysis of the resulting crashes (involving both computer runs and limited hard-copy accident report analysis) indicated that some were intersection/interchange related, some were "wrong-way" crashes, and some involved vehicles that had spun on icy roads and struck vehicles head-on in their own lanes—none of which were true "cross-median" crashes. To reduce possible biases in the rates, the data file was then screened to eliminate (as best possible) intersection accidents, accidents involving "wrong-way" vehicles, and accidents occurring during the six months when ice and snow were most probable.

Accident rates were then developed for nonbarrier situations on divided urban and rural interstates and freeways, and other roads, categorized by median width (0 to 10 ft [0 to 3.04 m], 11 to 30 ft [3.35 to 9.14 m] , 31 to 60 ft [9.45 to 18.29 m], 61 ft [18. 59 m] and over). Table 1 provides the results for one State during the 6-month analysis period, including the number of accidents, the amount of roadway mileage, and the accident rate.

Since all "biases" could not be eliminated from the rates, they are considered "best estimates" at this time. They are felt to be "liberal" (i.e., higher than true "cross-median" rates) since all biasing crashes (e.g. some head-on crashes due to spinning in the same lane) could not be screened out. They are perhaps "conservative" since they do not include single-vehicle crashes in which a vehicle crosses the median and strikes some roadside object or overturns rather than striking an oncoming vehicle.

Similar tables were developed in the other two States for divided highways without median barriers. An analysis and comparison of these results, further examination of hard-copy accident reports, and development of accident rates for divided highways with median barriers are underway. A full report documenting the results will be available later in 1991.

4: Head-On Accidents

The analysis examples cited previously have all required significant effort to design the required data runs, compile the necessary data, and analyze the results. The following problem analysis, however, illustrates how the analyst can use the HSIS to quickly access information about a particular type of accident to grasp the scope of a problem or to check trends.

Problem

Although head-on accidents occur infrequently, they often result in severe injuries to vehicle occupants. Moreover, highway safety professionals recognize that their efforts are best devoted to planning programs or policies in those areas where the potential reduction in severe injury is the greatest. Therefore, a problem identification analysis of head-on accidents was conducted. Its purpose was to provide better information regarding the extent of the head-on accident problem and the conditions under which these accidents occur.

HSIS analysis steps

To conduct a quick examination of the head-on accident problem in the HSIS States, analysts reviewed recent data for four of the HSIS States.

Table 1.—Median crossover accident rates (2)

	Urban Interstate/Freeway			Urban Other		
Median Width	Rate[a]	Miles	Accidents	Rate	Miles	Accidents
1-10	—[b]	—	—	3.95	105	50
11-30	0.93	17	4	2.17	137	34
31-60	0.13	135	3	0.55	85	4
61+	0.35	143	5	0.00	7	0

	Rural Interstate			Rural Other		
Median Width	Rate[a]	Miles	Accidents	Rate	Miles	Accidents
1-10	—	—	—	—	—	—
11-30	—	—	—	0.61	61	1
31-60	0.00	221	0	1.40	76	6
61+	0.13	1,265	9	0.00	19	0

[a]Rates are in accidents per one hundred million vehicle miles.
[b]Insufficient raodway mileage available.

The first step was to examine the extent and severity of the problem by comparing the head-on accident data to that for all accidents.

As shown in table 2, while head-on accidents are a small part of the total accident problem, they comprise a significant percentage of all fatal accidents.

The second step was to isolate conditions under which head-on accidents occur; here, the proportion of total accidents was compared to the proportion of head-on accidents occurring under key environmental and roadway conditions.

Since the results were consistent across the States, the data were combined to produce the following figures. Figure 5 indicates that ice and snow road surface conditions are overrepresented in head-on accidents. Figure 6 shows that the dark and dark-with-street-light conditions are overrepresented in head-on accidents. Finally, Figure 7 illustrates that head-on accidents are more likely to occur on curves.

A full investigation of the head-on accident problem would require additional analysis of the interaction of these variables—light, road surface conditions and roadway alignment—and a comparison with data from non-snow States. However, this example illustrates how the HSIS can quickly provide information on the extent of a problem and potential contributing factors.

Table 2.—Comparison of head-on accidents with all accidents

State (1)	Head-On accidents (2)	Head-On fatals (3)	All accidents (4)	All fatals (5)	Head-On percent (2)/(4)	Fatal percent (3)/(5)
1	5,319	432	492,812	2,442	1.1	17.7
2	8,951	394	429,959	1,762	2.1	22.4
3	5,257	225	218,158	1,503	2.4	15.0
4	1,986	68	141,802	819	1.4	8.3

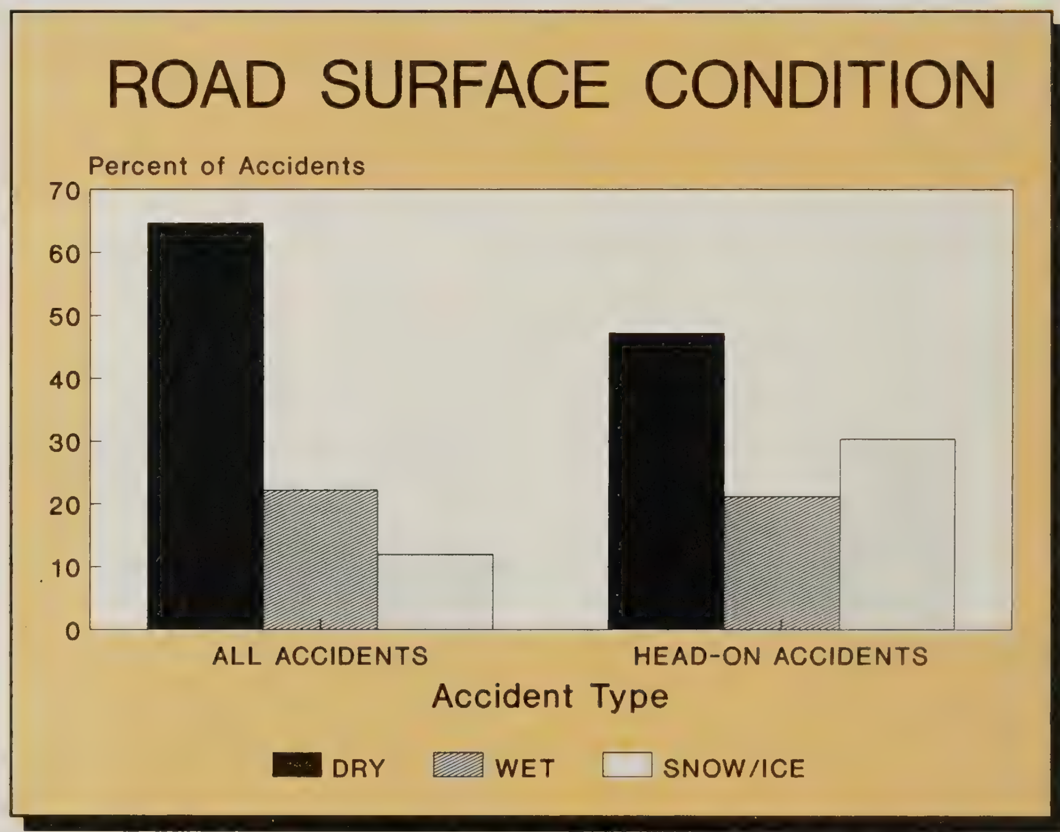

Figure 5.—Effect of road surface condition on accidents.

5: Urban Freeway Lighting

This problem analysis example illustrates a situation where the HSIS contains the necessary accident data and some of the required roadway information, but where additional non-HSIS data are also needed.

Problem

Nationwide accident statistics show that more than 50 percent of fatal accidents occur during the hours of darkness. Because travel statistics show that only 25 percent of travel occurs during the same period, the fatality rate is actually nearly three times higher at night than during the day.

The installation of overhead lighting is a potential countermeasure to this nighttime accident problem. However, this is expensive, and because research to date offers conflicting results about its cost effectiveness, an HSIS study is being conducted to examine the potential benefit of using lighting in high-volume situations such as urban freeways.

HSIS analysis steps

Although the investigation of the cost effectiveness of urban freeway lighting is still in its early stages, a significant effort has been devoted to assembling the necessary information. An examination of the HSIS data files revealed that the desired accident and roadway variables were present, but none of the States had complete lighting information. Moreover, the traffic data in the HSIS provides an indication only of the average daily traffic, not the 24-hour distribution needed to develop day versus night accident rates.

The next step was to determine whether the HSIS States had additional noncomputerized files that could provide lighting information and traffic data. Because the missing data were lighting and traffic

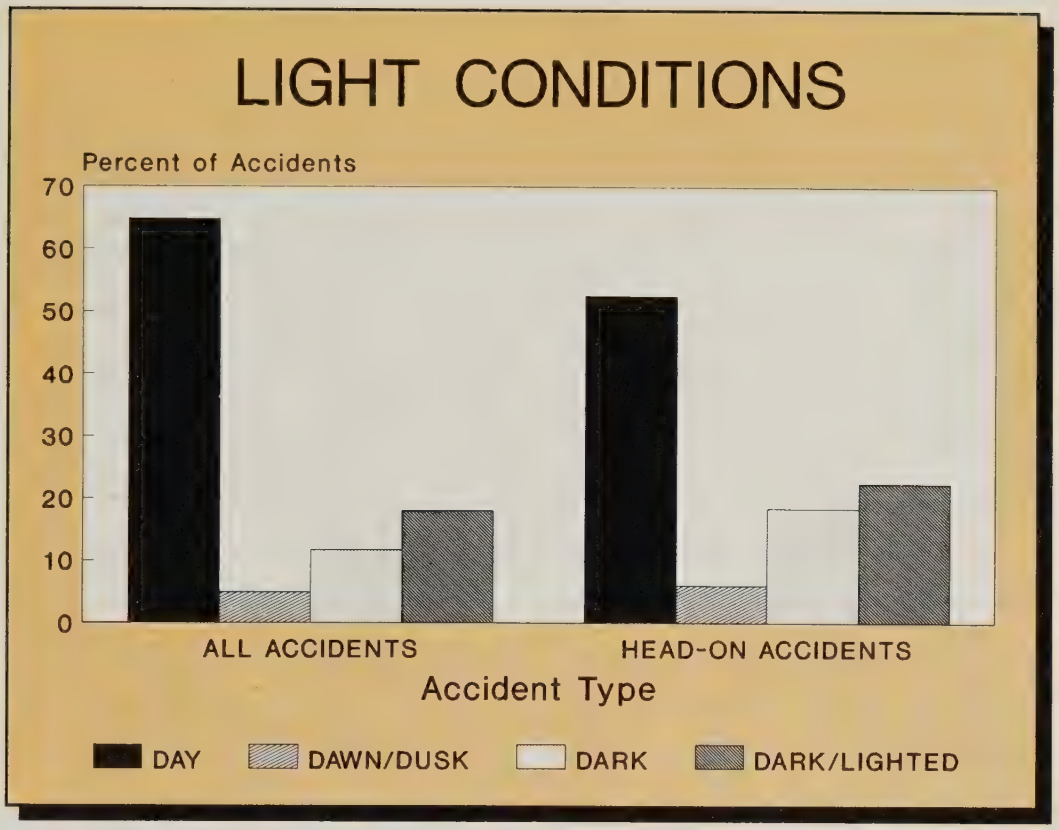

Figure 6.—Effect of light conditions on accidents.

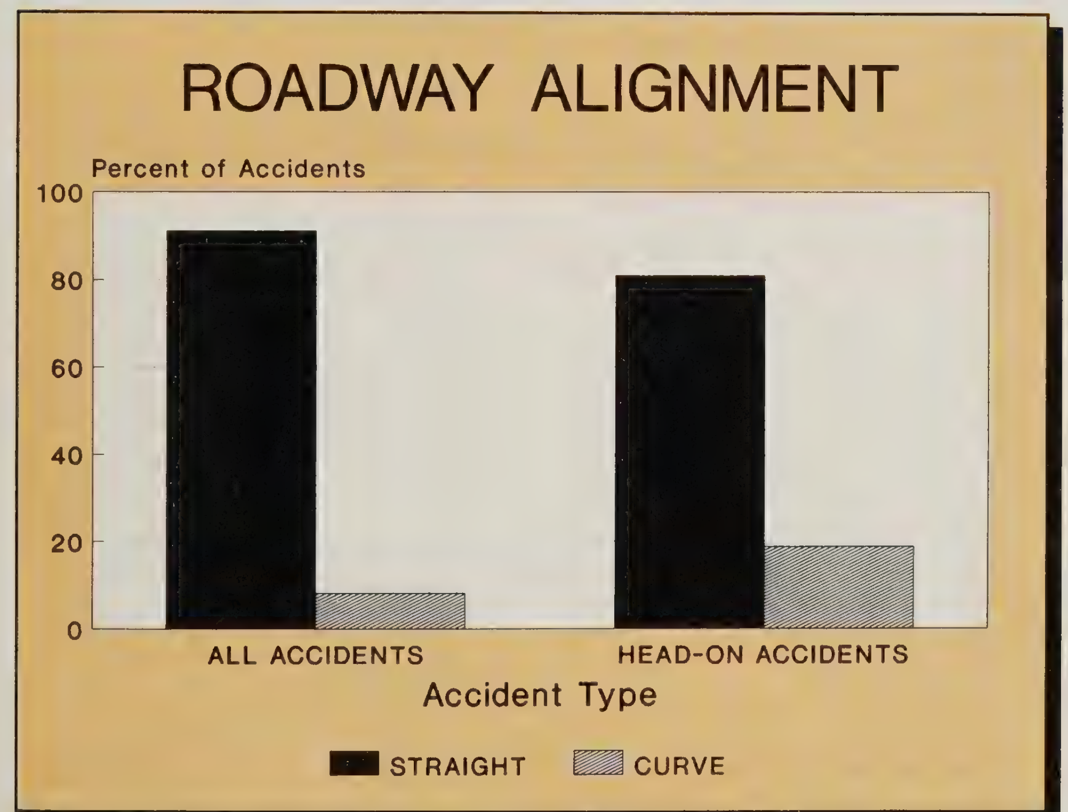

Figure 7.—Effect of roadway alignment on accidents.

information for urban freeways, the three HSIS States with large urban areas were contacted first. Two of the three States provided information about the locations, type, and installation dates of lighting along urban freeways, as well as 24-hour traffic distributions from automatic traffic recorders.

This information provided by the States is now being matched with the existing HSIS accident, roadway, and traffic files, and sunrise/sunset information provided by the U.S. Naval Observatory for a more precise assessment of accident occurrences.

This problem analysis example demonstrates how both HSIS and non-HSIS data can be combined to address a safety question. While, the HSIS accident, roadway inventory, and traffic files will often provide the "core" variables, they frequently must be supplemented by field data collection or acquisition of noncomputerized data files.

The Future of the HSIS

Although the HSIS is now fully operational, it is intended to be a dynamic data base that will adjust to meet the changing needs for safety data. To do this will require a periodic assessment of how well the system is functioning and an identification of potential modifications. The HSRC under contract from the FHWA is conducting such an evaluation. Having converted the HSIS to a microcomputer-based system, the HSRC is charged with two other broad provisions to:

- Use the system for wide range of analysis activities.
- Evaluate the system to determine if modifications or enhancements are required.

Analysis activities

To date, more than 15 HSIS analysis projects have been identified; they include completed or ongoing efforts by HSIS contract staff, FHWA researchers, FHWA graduate research fellowship students, and outside contractors. To fully evaluate the system's effectiveness, the HSIS must be used for a wide range of analysis activities. While it is expected that many of these analysis activities will be short term responding to current issues, several long-range studies have been planned. These include studies of:

- Truck accidents that will examine the relationship between truck accidents and highway characteristics—horizontal curvature, vertical grades, lane width, etc. The study will develop predictive equations for use in identifying deficient highway sections.

- Roadside hazards that will develop a severity index to quantify the effects of roadside hazards on accident severity. This index could be used to evaluate the cost effectiveness of roadside improvements—relocating utility poles, breakaway sign supports, crash cushions, etc. Both HSIS and non-HSIS data sources will be used.

- Intersection accidents that will isolate the intersection characteristics that are overrepresented in accidents such as number and type of lanes, intersection geometry, traffic volume, traffic distribution, etc.

System enhancements

In planning for the future of the HSIS, a number of system enhancements are being examined, including those for improving the user-friendliness of the system and for adding new States or additional data files to the system.

In the near term, enhancement efforts will concentrate on improving the data available for the existing HSIS States. Data enhancements include:

Using vehicle identification numbers (VIN). A VIN is a unique number assigned to each manufactured vehicle. Processing the VIN through an available decoding program will generate information on the size and weight of the vehicle. These data are useful for studying the performance of roadside hardware and the handling of vehicles on certain roadside geometrics.

Merging of a cross-section data base. A detailed cross-section data base was developed for 4,950 mi (7 966 km) of roadway in seven States—two of which are HSIS States—as part of an earlier FHWA effort. Merging this cross-section data base with the current HSIS data files would provide access to information not available in any roadway inventory file in the U.S. New information generated would include: roadside recovery distance, a subjective roadside hazard rating, the number of and distance to roadside obstacles (utility poles, trees), and sideslope data.

Linking with the Highway Performance Monitoring System. Currently, each State reports to the FHWA highway features and traffic data for a sample of their highway sections. The data are used to compile national statistics. They could also be used to supplement the existing HSIS data files. Potential variables include: pavement roughness, passing sight distance, design speed, and roadway capacity.

Using bridge/railroad crossing files. These files were recently acquired for each State. Due to time limitations, however, the raw files have not yet been converted to SAS format. The bridge files contain information on bridge width, railing type, guardrail transitions, etc. The railroad files contain data on the crossing geometry, type of protection, train volumes, etc.

Using videodisc photologs. A least one HSIS State has photologs (pictures taken each 0.01 mi [16.09 m]) available on videodisc for the entire State-maintained highway system. Videodiscs, which are similar to the compact discs used for storing audio information, allow the photolog pictures to be efficiently stored (500 or more mi [804.7 km] per disc) and rapidly accessed. Videodiscs would provide the capability to collect "new" roadway inventory data from an office setting. This data could include the locations of fixed lighting, speed limits, or roadside hardware.

Conclusion

The five problem analysis examples illustrate that the HSIS can be used for a range of tasks, from performing basic problem identification using only one file to developing accident rate models, to performing analyses of complex problems using HSIS data in combination with supplemental data. By incorporating accident, roadway inventory, and traffic data files from five different States, the system can be used to study numerous issues and provides the ability to check the consistency of findings across States. Planned enhancements will increase the flexibility of the system and its range of applications. As with any data system, the long-term success of the HSIS will depend on the expertise, inquisitiveness, and innovation of its users.

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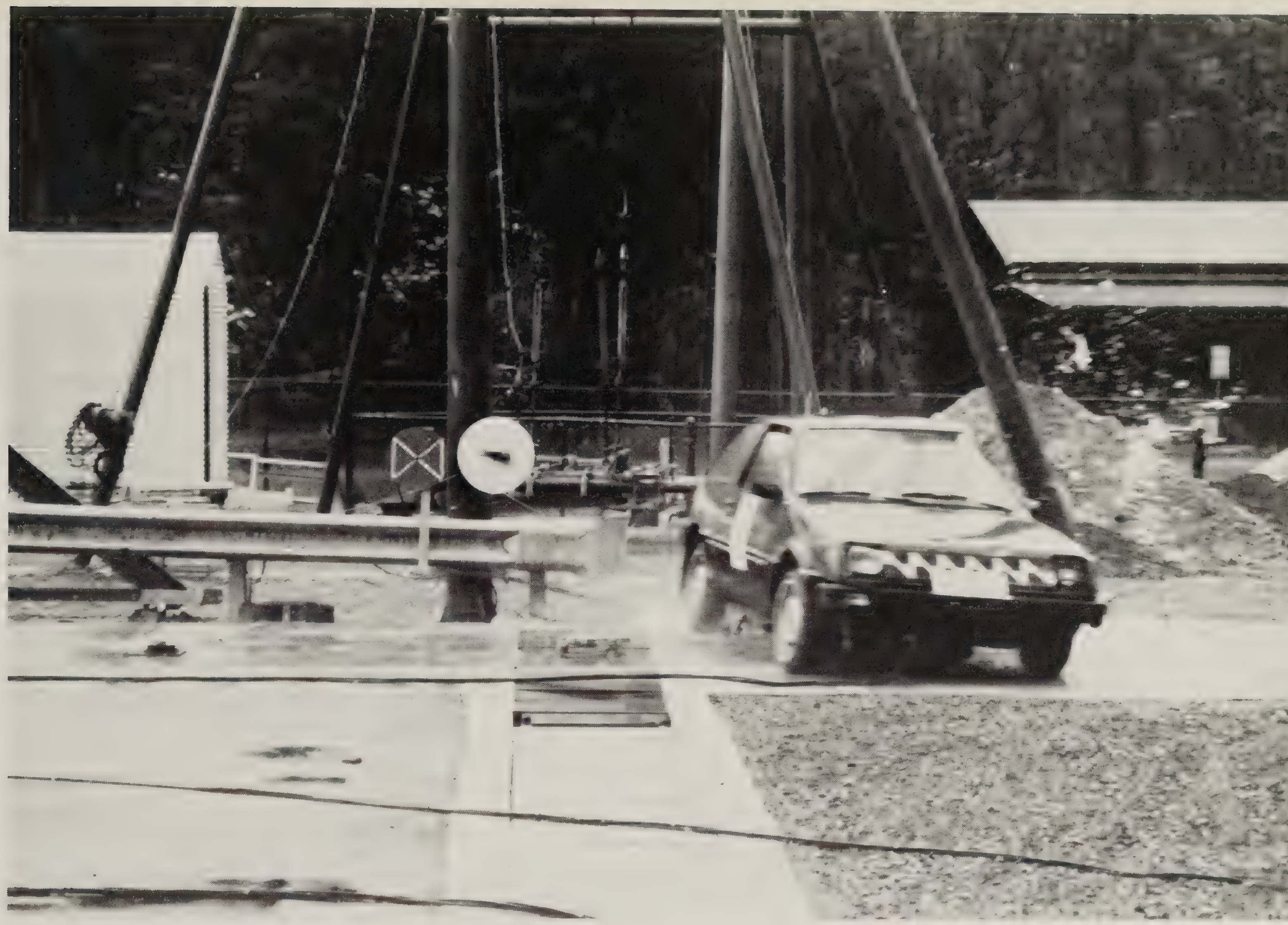
Forrest M. Council is deputy director of the University of North Carolina Highway Safety Research Center. He is currently the principal investigator on the study involving the maintenance, enhancement, and analytical use of the Highway Safety Information System (HSIS) for the FHWA. Since 1968, his work at the research center has involved roadway safety using State data files. He served as principal investigator for the project in which the HSIS was developed.



Full-Scale Side Impact Testing

by Allen G. Hansen

Introduction

Each year, approximately 12,000 people are killed in run-off-the-road single-vehicle collisions with fixed roadside objects and roadside features. Over 20 percent of these fatalities are collisions with a vehicle side, more than half of which are due to impacts with three types of roadside objects: trees, utility poles, and other poles and signs.

This article describes recent research involving mini-size cars impacting sideways into breakaway luminaire supports. This research was conducted to:

- Determine the types and causes of occupant injuries that occur during these impacts.
- Develop preliminary test evaluation criteria linking injury potential to vehicle rather than to dummy results. The vehicle test was employed to simplify the test and reduce costs.

The Side Impact Problem

Side impact accidents can result in vehicle velocity changes similar in magnitude to those experienced during frontal impacts. An additional frequent complication of side impacts is intrusion by the impacted object into the occupant compartment. Intrusion can lead to severe injuries to the head and thorax. It generally occurs when the side of a vehicle impacts a narrow object at or near the occupant compartment: this is because there is little vehicle side structure available to absorb the energy of impact. Breakaway sign and luminaire supports can also cause intrusion since breakaway often occurs long after the support has intruded into the occupant compartment.

Currently, side impact injury severity estimates are based on analysis of anthropometric dummy data. The primary measure of severity is the thoracic trauma index (TTI), which is a composite figure obtained from accelerometers located in the dummy's thorax. The TTI values are used in conjunction with the abbreviated injury scale and the occupants's age to determine the probability of injury.

A secondary measure of severity is the head injury criteria (HIC). The HIC are based on accelerations of the dummy head and neck; however, these are currently calibrated for frontal impacts only. For frontal impact conditions, HIC-values exceeding a threshold of 1,000 are considered to produce life-threatening or fatal injury. Although this threshold is not applicable for side impacts, it may be assumed that (1) very high values can be expected to produce severe injuries, and (2) HIC values can be compared when the same dummy is used in the tests.

The Test Program

Eight side impact tests were conducted at the Federal Outdoor Impact Laboratory (FOIL) using 1,850-1b (840-kg) Dodge/Plymouth Colts. All tests were conducted with the vehicle aligned broadside with the line of travel; impacts with luminaire supports were made at a speed of 30 mi/h (13.4 m/s). An unrestrained anthropometric dummy was positioned in the driver's seat during each test to measure occupant injury.

The tests measured the performance of two types of breakaway luminaire supports: slip base and transformer base. The slip base support is one of the safer breakaway supports now in use; the transformer base support, on the other hand, is the most commonly used.

Both vehicle- and dummy-based measures of injury severity were obtained during the tests. The vehicle-based measures taken were (1) flail space change in velocity, which is an estimate of the vehicle occupant's impact velocity; (2) vehicle static crush depth; and (3) crush location. The dummy-based measures comprised both TTI and HIC values.

Results and Comparisons

Table 1 summarizes results of the eight impact tests. (*1*)[1] Tests 1, 3, and 4 were conducted to provide a baseline for slip base performance. Test 8 duplicated these three tests, but also measured the significance of bolt tension in the supports: in test 8, the supports' mounting bolts were only finger tight. The results

[1]Italic numbers in parenthesis identify references on page 282.

Table 1.—Summary of test results

Test number	Impact location (in)	Test article	Flail space velocity change (ft/s)	Maximum static crush (in)	TTI-86	HIC	Comments
1	0 (at occupant)	Slip base	9.7	10.0	208	1,590	
2	0	Transformer base	26.7	26.0	348	3,390	Test article did not break away
3	0	Slip base	6.1	9.5	281	8,680	
4	0	Slip base	9.1	10.0	250	8,030	
5	-12 near B pillar	Slip base	11.4	13.0	121	60	
6	+12 near door center	Slip base	28.8	36.0	183	2,190	Test article did not break away
7	+24 near A pillar	Slip base	14.7	7.7	71	150	
8	0	Slip base	7.1	7.5	148	2,000	Test article mounting bolts finger tight

1 in = 25.4 mm
1 ft/s = 0.305 m/s

showed that even with no bolt tension, the inertia of the luminaire support caused significant vehicle crush and occupant injury. Test 2 was run to provide a comparison of the transformer base to the slip base.

Tests 5, 6, and 7 revealed how injury severity diminishes as the impact location moves away from the occupant. Finally, in tests 2 and 6, the luminaire supports did not break away, leading to both occupant injury and severe vehicle crush.

Thoracic injury comparisons

Several of the tests were conducted at different locations along the vehicle's side. Comparing thoracic trauma and impact location data yields a correlation coefficient of 0.85, indicating a significant correlation between the TTI and crush location. Figure 1 shows the predicted thoracic trauma versus impact location for tests with essentially equal breakaway force. The absolute value of the impact location relative to the dummy was used to obtain a uniform curve.

Comparing flail space velocity change data to thoracic trauma data obtained in tests with identical impact locations resulted in a moderate correlation. Moderate correlation also resulted when static crush depth was compared to thoracic trauma with the same limited data set.

Head injury comparisons

As expected, the HIC value is much larger when the dummy head comes into direct contact with the object impacted. However, when HIC values were compared to flail space velocity change values, there was little correlation, even when the data were limited to those tests with identical impact locations. Similarly, HIC values showed no correlation with static crush depth. This lack of correlation perhaps reflects the fact that the dummy has not been designed and validated for impacts to the side of the head.

Conclusions

Roadside objects are "unacceptable" during side impacts. Accidents similar to many of the tests in this series result in near-certain severe or fatal injury. Incidents that would be considered mild low-speed accidents if the occupant compartment had not been impacted often result in violent outcomes.

Simply stated, side impacts with their consequent problem of intrusion can be more deadly than frontal impacts. However, much of the roadside hardware and design guidance now in use has been developed to address frontal impacts. For example, breakaway luminaire supports, which generate acceptable impact severity indicators during frontal impacts, often generate highly unacceptable indicators during side impacts. Also, the lateral flail model now in use specified by the Federal Highway Administration is designed for impacts such as glancing blows into guardrails and other longitudinal barriers; it was not intended to measure occupant injury during impacts where intrusion occurs.

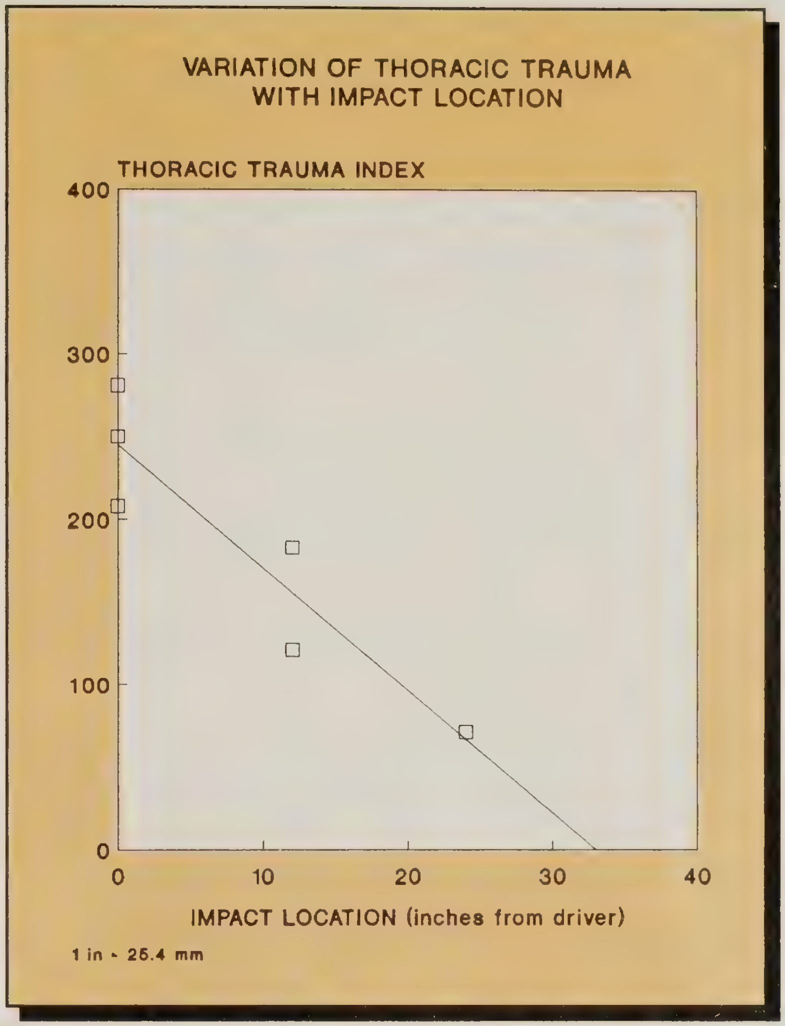


Figure 1.—TTI-86 versus impact location.

Moreover, in evaluating roadside objects, test articles are considered unacceptable when intrusion of the occupant compartment occurs. Consequently, if this criterion on performance was applied to side impacts into narrow roadside objects, very few—if any—luminaire supports, sign supports, and barrier end terminals would be qualified as acceptable.

To remedy this situation of non-qualifying roadside hardware, intrusion could be broken out into two types: (1) protrusion or puncture of a test article into the occupant space, such as a guardrail beam spearing into the car, which should not be considered acceptable; and (2) controlled occupant compartment deformation, where intrusion could be accepted if occupant injury levels are mitigated. Implementation of these categories would enable qualification of much of the roadside hardware in use today.

More test and data are needed. More tests are needed to better characterize the relationships between occupant injury and both flail space velocity change and static crush depth. Such tests should include testing at both lower and higher impact speeds into the slip base luminaire supports as well as higher severity impacts into different supports. These tests would provide data needed to better define these relationships, thereby obtaining significant correlations. Side impact tests involving fixed roadside objects could then be conducted without a dummy while maintaining the ability to predict occupant injury.

Enhance cars' side structures to decease injury. Currently available small cars lack stiffness in their side structure. Consequently, even moderate static crush may result in serious to fatal thoracic injury. Such injuries occur because:

- Many side impact accidents involve collisions with non-breakaway roadside objects such as trees and utility poles.
- Accidents with breakaway supports—even the best supports now available—result in significant intrusion before the device breaks away.

An increase in the side stiffness of small cars—particularly at the lower sill and the upper roof line—should reduce injury potential.

Recommendations

Improve the design of breakaway luminaire supports. The fact that one slip base and the transformer base did not break away indicates that design improvements are needed for breakaway luminaire supports.

Investigate techniques to limit head contact or mitigate head trauma. During all tests conducted directly in line with the dummy, substantial head contact and resultant high HIC values occurred. To reduce or eliminate such injuries will require techniques to limit head contact or mitigate head trauma.

Investigate techniques to minimize or reduce intrusion of the narrow support into the occupant compartment. Such techniques will help decrease existing levels of thoracic and pelvic injury.

Reference

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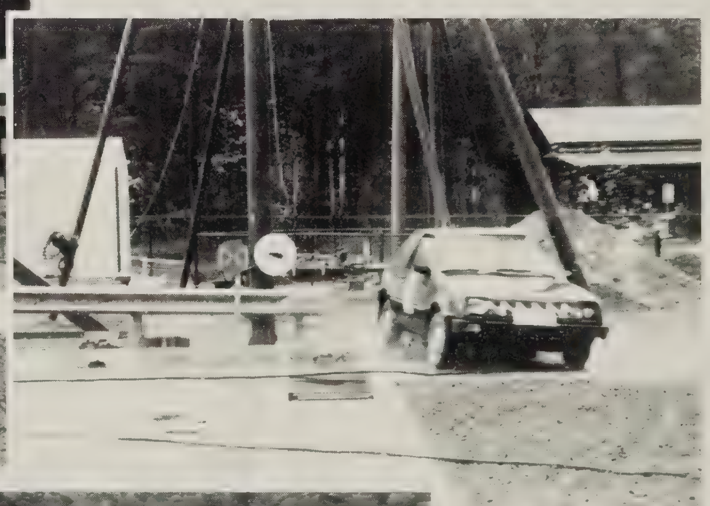
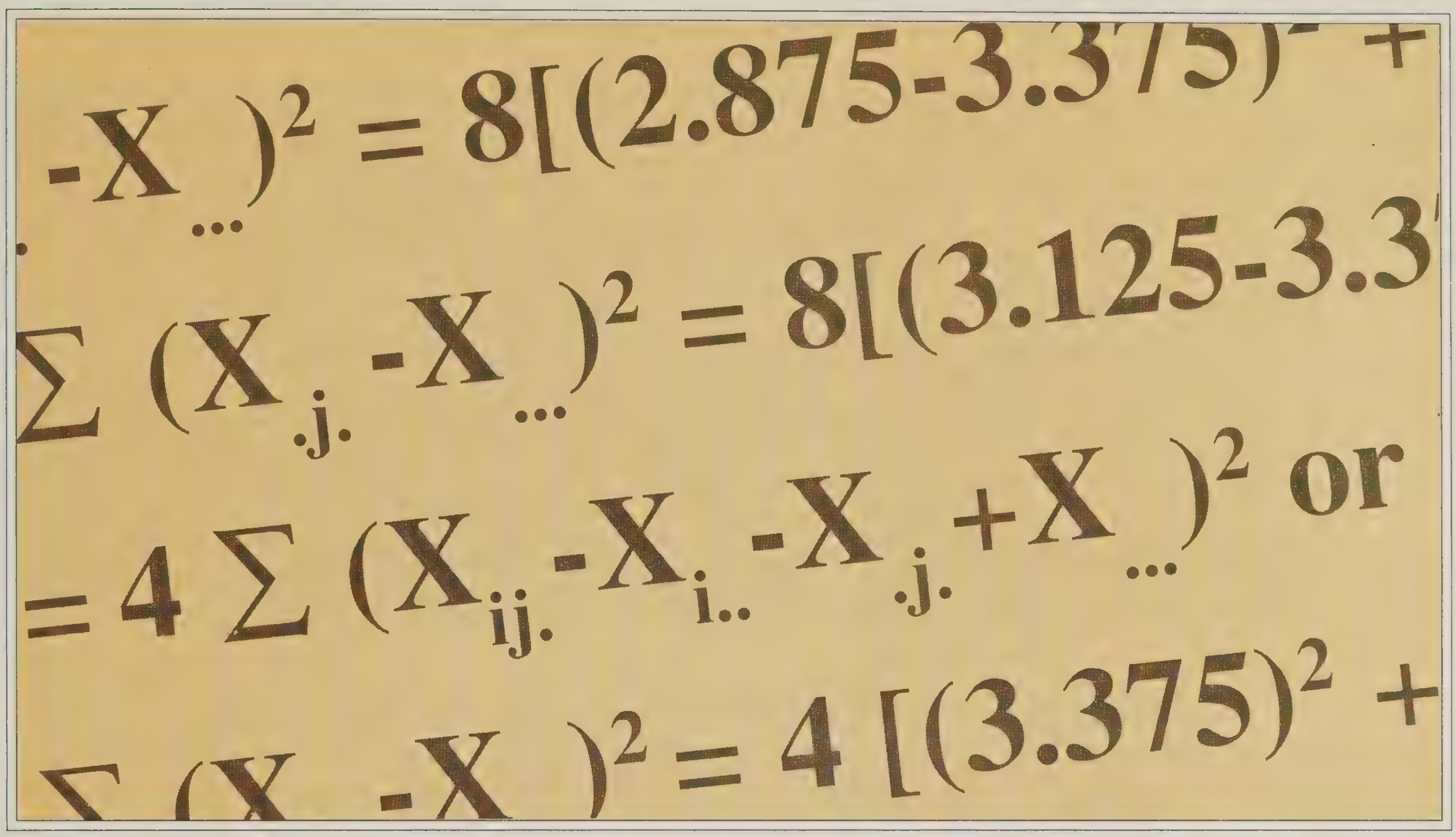
Allen Hansen is a mechanical engineer and director of the Engineering System Division of The Scientex Corporation. He currently manages and is the principal investigator on several highway safety research projects being conducted for the Federal Highway Administration.



Full-scale side impact crash test.



Statistical Shortcomings in Traffic Studies

by Harry S. Lum

Introduction

Over the years, the Federal Highway Administration (FHWA) has been receiving more and more research reports in which the authors use statistical techniques of analysis of variance and regression analysis. Many of these studies are flawed due to a lack of understanding of the assumptions underlying these statistical techniques. Consequently, the findings and conclusions presented in the reports may be open to question and challenge. A possible explanation for the lack of understanding of the meaning of statistical interaction is that researchers depend too much on computer software packages to do their analysis, and not enough on their own statistical interpretation abilities.

The purpose of part I of this two-part article is to review factorial design, discuss the requirements for an accurate analysis, and highlight some analytical shortcomings and instances of invalid and incomplete data analysis. Since factorial design is most often used by traffic researchers, a clear understanding of this statistical technique is critical. Part II, to appear in the next issue of *Public Roads*, will discuss the advantages and disadvantages of the factorial design in practice.

Analysis of Variance: Factorial Design

Traffic accidents are usually due to a combination of factors. For example, drivers may experience no problem in maneuvering their vehicles safely around a horizontal curve in daylight hours, but may have difficulty doing so at night in dense fog. The usual approach to investigating the effect of two or more independent variables (e.g. night, fog) on a particular dependent variable (e.g. ability to remain on the road) is the *factorial design* in the framework of analysis of variance. These factorial experiments are sometimes referred to as *cross classification experiments.* The independent variables are often referred to as *factors* or *treatment factors* because they can be manipulated; the dependent variable is known as the *response variable.* The *subclassification* of a factor is called the *level.* For example, male and female would be the levels under the treatment factor "gender". The major assumptions underlying a factorial experiment include a design in which sample sizes are equal and observations which are taken from a normally distributed population.

Evolution of Experimental Design

In the early days, when experimentation was mostly performed in controlled laboratory environments, the usual procedure was to examine

Table 1.—Layouts of a single factor (a) and a factorial experiment (b)

(a)

Layout of single factor experiment	Driving experience: Factor A		
Traffic sign Factor B	Less than 1 year	More than 1 year	
	a_1	a_2	Totals
	10	10	20
Driving Experience Factor A	Traffic sign Factor B		
	Proposed sign	Current sign	
	b_1	b_2	Totals
	10	10	20
Totals	20	20	40

(b)

Layout of factorial experiment		Driving experience: Factor A		
		Less than 1 year: a_1	More than 1 year: a_2	Totals
Traffic sign Factor B	Proposed sign b_1	5	5	10
	Current sign b_2	5	5	10
Totals		10	10	20

one factor at a time at different levels or subclassifications. Consider the following experimental layout, illustrated in table 1-a. In a single factor experiment of driving experience (factor A), a comparison is made between the two levels of driving experience—a_1 (less than 1 year) and a_2 (more than 1 year)—at some fixed level of another factor, say traffic signs (factor B)—either b_1 (proposed sign) or b_2 (current sign). Similarly, for the single factor B experiment, a comparison is made between the two levels of the traffic sign b_1 (proposed) and b_2 (current) at some fixed level of factor A (driving experience).

The noted statistician Sir Ronald A. Fisher pointed out that a more efficient and economical analytic approach was to combine the different factors in a single experiment, called a *factorial experiment.*(*1*)[1] Using this method, the researcher compares all treatment options by combining the levels of the different factors. The method thus allows the researcher to measure the joint effect of two (or more) factors simultaneously. In a simple 2 by 2 factorial experiment which examines the interactions of two variables, the treatment combinations are a_1b_1 (inexperience, proposed sign), a_1b_2, (inexperienced, current sign), and so on for a_2b_1, and a_2b_2.

Factorial Design

The factorial design method has many advantages over the single-factor method, as the following example illustrates. Suppose 20 experimental units (e.g. subjects) were available for a given two-variable study each with two levels. In a factorial experiment, the subjects would be randomly assigned to one of four cells for a total of five subjects in each cell as shown in table 1-b. An important requirement for factorial design is equal frequency or, for this case, equal numbers of subjects in each cell. In the single factor experimental approach, the researcher would conduct the experiment comparing a_1 with a_2 at some fixed level of factor B, say b_1. At the end of the experiment the researcher could conclude which level of factor A is "better," a_1 or a_2. For the second experiment, by comparing b_1 with b_2 and some fixed level of factor A, say a_1, the researcher could conclude which is better, b_1 or b_2.

In the first experiment no information is available as to whether a_1 and a_2 will respond similarly or differently at the b_2 level of factor B since the experiment was conducted at the b_1 level. Likewise for the second experiment, no information is available on the two levels of factor B at the a_2 level since the experiment was conducted with the a_1 level. The factorial design overcomes this shortcoming; it can provide the "missing" information.

For a single-factor experiment, 10 subjects would be assigned to each level of driving experience and another 10 subjects to each level of the traffic sign. Therefore, a total of 40 subjects would be required for the two single-factor experiments, as compared to 20 for the factorial experiment. Had the researcher

[1]Italic numbers in parenthesis identify references on page 287.

used only 10 subjects for each single-factor experiment, however, the experiments would be considered less efficient. Thus, besides providing information on the joint effect of two factors simultneously, factorial design is a more powerful statistical tool than single-factor.

The following example illustrates how the factorial design works. Simply put, the difference in the responses (i.e., the recognition distance of the sign) for the treatment combinations $a_2b_2 - a_1b_2$ estimates the effect (called simple effects) of the traffic sign (factor B) on driving experience (factor A) at the fixed b_2 (current sign) level; $a_2b_1 - a_1b_1$ measures the effect of the traffic sign (factor B) on driving experience at fixed b_1 (proposed sign) level. The average of the two estimates between the two comparisons is called the factor's *main effect*, i.e.:

Main effect of factor A =
$1/2[(a_2b_2) + (a_2b_1) - (a_1b_2) - (a_1b_1)]$
Main effect of factor B =
$1/2[(a_2b_2) + (a_1b_2) - (a_2b_1) - (a_1b_1)]$

If the experiment is replicated *n* times, the cell response values are the average of the number of replications.

Statistical Assumptions

Statistical tests of significance assume that each observation (i.e. sign recognition distance) comes from a normally distributed population with a common variance and with a mean that is the sum of four components (plus random error):

Observed value = grand mean + row effect + column effect + combination of row-column effect + random error

Table 2.—Artificial data for a 2 by 2 factorial experiment

cell (1,1)	cell (1,2)	total (row 1)
data 2,3,3,4 total = 12 mean = 3 ssq = 2 # of obs = 4	data 2,3,3,3 total = 11 mean = 2.75 ssq = .75 # of obs = 4	total = 23 mean = 2.875 ssq = 2.75 # of obs = 8
cell (2,1)	**cell (2,2)**	**total (row 2)**
data 3,4,4,2 total = 13 mean = 3.25 ssq = 2.75 # of obs = 4	data 4,4,5,5, total = 18 mean = 4.5 ssq = 1.00 # of obs = 4	total = 31 mean = 3.875 ssq = 3.75 # of obs = 8
total (column 1)	**total (column 2)**	**overall**
total = 25 mean = 3.125 ssq = 4.75 # of obs = 8	total = 29 mean = 3.625 ssq = 1.75 # of obs = 8	total = 54 mean = (54/16) = 3.375 ssq = 6.5 # of obs = 16

Note: The numbers inside the parenthesis are in lexicographic order. The first number stands for the level of factor A and the second stands for the level of factor B. For example, cell (2,1) stands for the second level of factor A and the first level of factor B.

data = actual observations in hundreds of feet
total = sum of observation is the summation of the squared difference among each observation and the mean
mean = average of observations
ssq = sum of square
# of observations = number of times for sign recognition distance

The contrived data in table 2 illustrate how the factorial experiment enables efficient analysis. The experiment is replicated four times, i.e., each cell has four observations. The cell *total*, the *mean*, and the *sum of squares*—adjusted by the cell mean—are given to facilitate the computation of the analysis of variance table shown in table 3.

In table 3, the number to the left of the summation sign denotes the number of observations used in the calculation of the effect (row, column) means.

This method of computing the sums of squares for various components by their definition is needlessly lengthy. It is much more convenient and easier to work with the totals (row, column, etc.) than with the means themselves. However it provides little understanding of the analysis. Note that the interaction sum of squares can be found by subtracting the sums of squares for row and columns from the subtotal sum of squares. Similarly the *within sum of squares* can be found by subtracting the subtotal from the total sum of squares. This property can be shown to hold only if the number of observations in each cell is equal. The measure of the joint effect of the two factors is the *interaction term* in the analysis of variance table.

The Null Hypothesis

The null hypothesis determined at the start on an experiment, is an assumption that the observed difference between two samples of a population is pure chance.

The researcher takes this data and its analysis and tests it for the truth or falsity of the null hypothesis. For this example experiment the statistical null hypotheses to be tested were as follows:

1. The row effects are zero and independent of the column effects.
2. The column effects are zero and independent of the row effects.
3. The row-column effects are zero and independent of the row effects and the column effects. In other words, there is no difference in the means of the sub-

Table 3.—Analysis of variance for data of table 2

Component	Sum of Squares	d.f.	Mean square	F-ratio	P-value
Row	4.00	1	$4.00/1=4.00 = S_4$	$S_4/S_1 = 7.38$*	<.01
Column	1.00	1	$1.00/1=1.00 = S_3$	$S_3/S_1 = 1.85$	.20
Interaction	2.25	1	$2.25/1=2.25 = S_2$	$S_2/S_1 = 4.15$	.06
Subtotal	7.25	3			
Within	6.50	12	$6.50/12=.54 = S_1$		
Total	13.75	15			

*Statistically significant at the 1 percent level.

Where by definition the sum of squares for:

row $= 8 \sum_{i} (\bar{X}_{i..} - \bar{X}_{...})^2 = 8[(2.875-3.375)^2 + (3.875-3.375)^2] = 4.00$

column $= 8 \sum_{j} (\bar{X}_{.j.} - \bar{X}_{...})^2 = 8[(3.125-3.375)^2 + (3.625-3.375)^2] = 1.00$

interaction $= 4 \sum_{ij} (X_{ij.} - \bar{X}_{i..} - \bar{X}_{.j.} + \bar{X}_{...})^2$ or by the difference between the subtotal and the sum of row and column

subtotal $= 4 \sum_{ij} (\bar{X}_{ij.} - \bar{X}_{...})^2 = 4\,[(3.375)^2 + (2.75-3.375)^2 + (3.25-3.375)^2 + (4.5-3.375)^2] = 7.25$

within $= \sum_{ijk} (X_{ijk} - \bar{X}_{ij.})^2$ or by the difference between subtotal and total = 6.50

Total $= \sum_{ijk} (X_{ijk} - \bar{X}_{...})^2 = (2.0-3.375)^2 + (3.0-3.375)^2 + ... + (5.0-3.375)^2 = 13.75$

groups after each of the cell means have been "corrected" for row and column effects.

The F Distribution

The *F distribution* (named for its originator Sir Ronald Fisher), is the distribution of the ratio of two sampling variances when the null hypothesis of equal group means is true. If the group means are from populations with different means (under the assumption of equal variances), then the estimate of the variance based on the groups would be larger than the estimate based on the pooled (averaged) of the groups. If the observed means are spread out more than could be expected and if all the means come from samples from the same population, the null hypothesis is statistically rejected. Tables of the *F* distribution give the percentage of time that the *variance ratio* will exceed the tabulated *critical value.* To use these tables, researchers must choose the appropriate *degrees of freedom* associated with the variance in the numerator and in the denominator of the variance ratio. The researchers must also specify the *significance level*, i.e., the percentage of time that the ratio will exceed the tabulated critical values. By doing so the researcher can control the error in rejecting the null hypothesis.

In table 3, the *F*-ratio of the *row category* is equal to 7.38 with an associated *probability value* (*p*-value) of less than 0.01—i.e., there is less than 1 chance in 100 of getting a value greater than 7.38 for the *F*-value. The usual procedure for the researcher is to reject the null hypothesis that the row means, 2.875 versus 3.875, are not equal statistically but drawn from different populations (see table 2.) (Of course, it is possible that 2.875 and 3.875 could represent means of samples drawn from the same population with the difference due to sampling variation. The probability of such an erroneous conclusion is less than 1 chance in 100.)

On the other hand, the *F*-ratio for the column means of 1.85 with an associated *p*-value of 0.20 offers no strong indication that the column means 3.125 versus 3.625 are from different populations since 20 times in 100 an F value greater than 1.85 can be expected. Therefore, the null hypothesis is *not* rejected.

The *F*-ratio for the row-column is 4.15; the critical value taken from the table of *F* distribution is 4.75 at the 5-percent significance level. If a 5-percent level was chosen, the null hypothesis of no interaction would not be rejected since the observed *F*-ratio of 4.15 is less than the tabulated critical value of 4.75. (The *p*-value for 4.15 was calculated to be 0.06.) Just because 0.06 is greater than 0.05, the researcher should not blindly accept the null hypothesis. Rather, the researcher should examine the interaction hypothesis in light of the other hypotheses such as the difference between values (traffic signs; driving experience)—especially the highly significant row effect.

The researcher should next examine the residual effects which is used to analyze interactions. Following are the residuals for the data in table 2.

Cell (1,1) = (3.000 - 2.875 - 3.125 + 3.375) = +0.375
Cell (1,2) = (2.750 - 2.875 - 3.625 + 3.375) = -0.375
Cell (2,1) = (3.250 - 3.875 - 3.125 + 3.375) = -0.375
Cell (2,2) = (4.500 - 3.875 - 3.625 + 3.375) = +0.375

The interaction sum of squares (2.25) by direct calculation is equal to:

$(+0.375)^2 + (-0.375)^2 + (-0.375)^2 + (+0.375)^2 = 0.5625 \times 4 = 2.25$

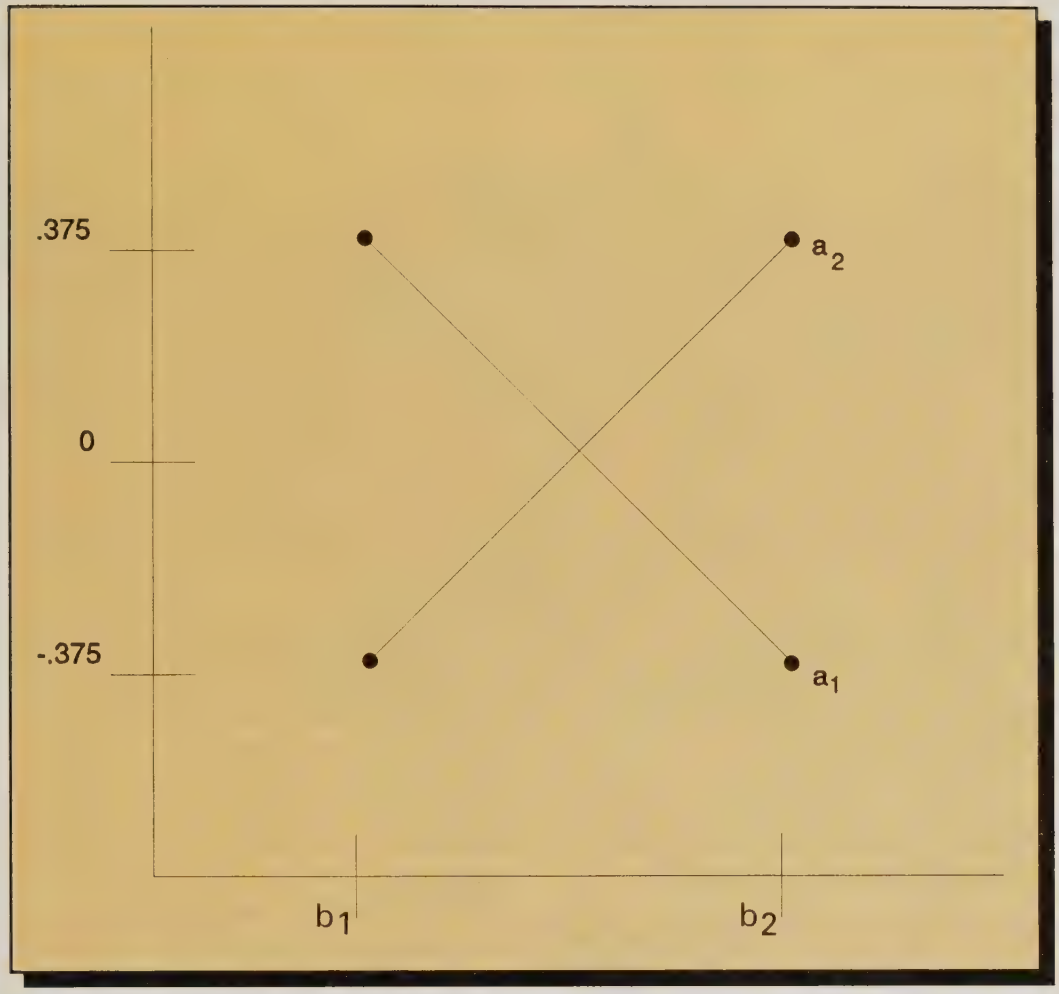


Figure 1.—Graph of residuals.

where 4 is the number of replications in each cell.

Example Review and Interpretation

To review the example: factor B (row) represents traffic signing with two levels: b_2 represents the current traffic sign; b_1 represents a proposed sign imparting the same message but with a different color configuration. And factor A (column) represents driving experience, where a_1 represents drivers with less than 1 year of experience and a_2 represents drivers with more than 1 year of experience. The response variable is the distance at which drivers recognize the meaning of the sign measured to the nearest 100 ft (161 km).

According to figure 1, the more experienced drivers perform better (i.e., longer recognition distance) than the less experienced drivers with the current sign, while less experienced drivers perform better with the proposed sign. What does this mean to the researcher? Since the traffic engineer may not install two sign configurations with the same traffic message, what is the conclusion? Further analysis shows that for the inexperienced drivers, the difference in recognition distance is .25, while for the experienced drivers, the difference is 1.75. The interaction term is statistically significant because of the large variation of the difference, i.e., .25 versus 1.75. Therefore, the conclusion in this example might be: the two sign configurations are statistically significant but of no practical importance.

Researchers need to provide the kind of analysis that shows interaction as demonstrated in the preceeding example with the X-shaped graph. This kind of analysis is usually lacking in traffic research reports. Common flaws in statistical analysis include the following:

- *Ranking the cell means.* Some researchers simply rank cell means. Cell means are not particularly meaningful when interaction is present. Moreover, ranking the cell means does not give a picture of the relationship of the interaction. An X-shaped curve drawn in figure 1 shows this type of relationship.

- *Not looking at combinations of means.* In many traffic accident studies, experiments focus on the interaction *between* treatments, but fail to investigate one practical significance or implications of the treatments themselves. Too often the investigator would present an analysis of variance table with a single asterisk after the *F*-ratio of the *interaction mean square* to indicate statistical significance at the 5-percent level or a double asterisk for the 1-percent level. Further analysis using residuals would provide the researcher with insight into the interpretation of the interaction term.(*2*)

- *Providing little interpretation.* Researchers sometimes merely present a table of the cell means, leaving readers on their own to interpret the results.

One reason for these gaps in interpretations may be an over reliance on computer software. Such software provides statistical information to the researcher, but does not necessarily explain or interpret the analysis. For example, only one computer software package has been identified to provide a residual analysis. (*3*)

References

(*1*) R.A. Fisher. *The Design of Experiment, 5th Ed.* Oliver and Boyd, Edinburgh, Scotland 1949.

(*2*) George W. Snedecor and William G. Cochran. *Statistical Methods, 6th Ed.* Iowa State University Press, Ames, IA, 1967.

(*3*) Ralph L. Rosnow and Robert Rosenthal. "Statistical Procedure and the Justification of Knowledge in Psychological Science," *American Psychologist*, 44 (October 1989): 1276-84.

Harry S. Lum is a mathematical statistician in the Design Concepts Division, Office of Safety and Traffic Operations Research and Development, Federal Highway Administration (FHWA). He has been with the FHWA since 1969, first as a member of the Urban Traffic Control System research team. Currently, he is involved with a Nationally Coordinated Program project on special highway users.

Recent Publications

The following are brief descriptions of selected publications recently published by the Federal Highway Administration, Office of Research and Development (R&D). The Office of Engineering and Highway Operations R&D includes the Structures Division, Pavements Division, and Materials Division. The Office of Safety and Traffic Operations R&D includes the Intelligent Vehicle-Highway Systems Research Division, Design Concepts Research Division, and Information and Behavioral Systems Division. All publications are available from the National Technical Information Service (NTIS). In some cases, limited copies of publications are available from the R&D Report Center.

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Cost-Effective Roadway Drainage Design Using Economic Analysis, Publication No. FHWA-RD-88-126

by Structures Division

This report describes a practical method for determining the road surface drainage design with the theoretical lowest total economic cost. The method, based on minimizing traffic delay costs, applies to freeways, arterials and major collectors. It uses a design rain to yield the most economical choices of gutters, inlets, and laterals considering both construction and risk costs. Three case studies are presented.

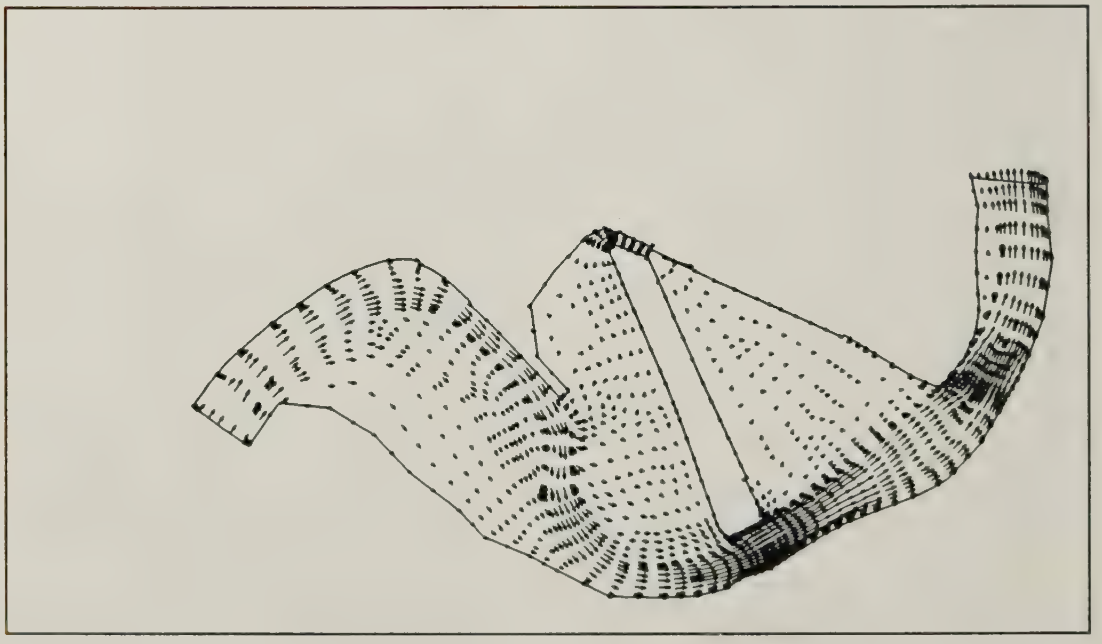
Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-104497/AS, price code: A11.)

Two-Dimensional Finite-Element Hydraulic Modeling of Bridge Crossings: Research Report, Publication No. FHWA-RD-88-146 (see illustration below)

by Structures Division

The U.S. Geological Survey in cooperation with the FHWA conducted a 6-year project to develop an accurate and easy to use model for analyzing backwater and flow distribution at highway crossings of rivers and flood plains. The finite-element surface-water flow (FESWMS-2DH) model is ideally suited to modeling two-dimensional flow over complex topography with spatially variable roughness. It allows the user great flexibility in defining boundaries, channels and embankments.

This publication may only be purchased from the NTIS. (PB No. 91-106492/AS, Price code: A08.)



Safety Implication of Various Truck Configurations, Vol. II: Appendixes, Publication No. FHWA-RD-89-019

by Design Concepts Research Division

This report provides results and findings from an analytical investigation of the influences of size and weight limits on trucks. Ultimately the work shows the manner in which size and weight rules influence the safety-related performance of vehicles designed to increase productivity. By treating a number of size and weight scenarios, the study has developed a basis for generalizing to principles that can be used in evaluating the possible safety consequences of changes in size and weight regulations.

This volume is the second in a series of three. The other two volumes are: Vol. I: Technical Report (FHWA-RD-89-018) and Vol. III: Summary Report (FHWA-RD-89-085).

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-108548/AS, price code: A08.)

Truck Characteristics for Use in Highway Design and Operation, Vol. II: Appendixes, Publication No. FHWA-RD-88-227

by Design Concepts Research Division

Highway geometric design and traffic operations are based, in part, on consideration of vehicle characteristics. However, many current designs are modeled for passenger cars, even though trucks may be more critical. This study uses existing data to determine appropriate geometric design and traffic operational criteria to accommodate trucks.

This volume documents the detailed investigation of six aspects of design and operational criteria for trucks.

Volume I (FHWA-RD-89-226) presents the main findings of the study, including recommended changes in the highway geometric design and operational criteria to accommodate trucks.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-106013/AS, price code: A11.)

Development of Additional Federal Outdoor Impact Laboratory (FOIL) Facilities, Final Report, Vol. II: Validation of the FOIL Pendulum Upgrade, Publication No. FHWA-RD-90-085

by Design Concepts Research Division

The pendulum of the FOIL simulates the low-speed impact of a small automobile into breakaway luminaire and sign supports. It has recently been upgraded with an 1800-lb (817-kg) mass, a new crushable nose design, special features to reduce harmonic ringing after an impact, and provisions for mounting onboard accelerometers. This report documents the design, development, and testing of pendulum.

This publication may only be purchased from the NTIS. (PB No. 91-108548/AS, Price code: A08.)

Automobile Impacts with Small Signs, Publication No. FHWA-RD-90-060

by Design Concepts Research Division

Small signs are classified as either breakaway or ridedown depending on their mode of failure. This report examines the physics of low-speed impacts of an automobile with small signs. The emphasis is on ridedown signs. Two models are defined. The results of the models are used to assess the important vehicle characteristics for impact conditions.

This publication may only be purchased from the NTIS. (PB No. 91-106021/AS, Price code: A06.)

Full-Scale Side Impact Testing, Publication No. FHWA-RD-89-157

by Design Concepts Research Division

This report discusses occupant injuries and fatalities due to single vehicle side impacts into roadside objects. It recommends means of strengthening vehicle sides, providing energy absorption for vehicle sides, and suggests criteria for future side impact research.

This publication may only be purchased from the NTIS. (PB No. 91-106047/AS, Price code: A05.)

Crush Characteristics of the 1800-lb Pendulum, Publication No. FHWA-RD-90-059

by Design Concepts Research Division

This report contains the results of tests performed to determine the crush characteristics of the FOIL 1800-lb (817-kg) pendulum. The pendulum was impacted into a rigid instrumented pole. The results were compared to similar tests in which 1979 Volkswagen Rabbits and the breakaway bogie vehicle were impacted into the rigid pole. The pendulum accurately represented the crush characteristics of the Volkswagen Rabbit.

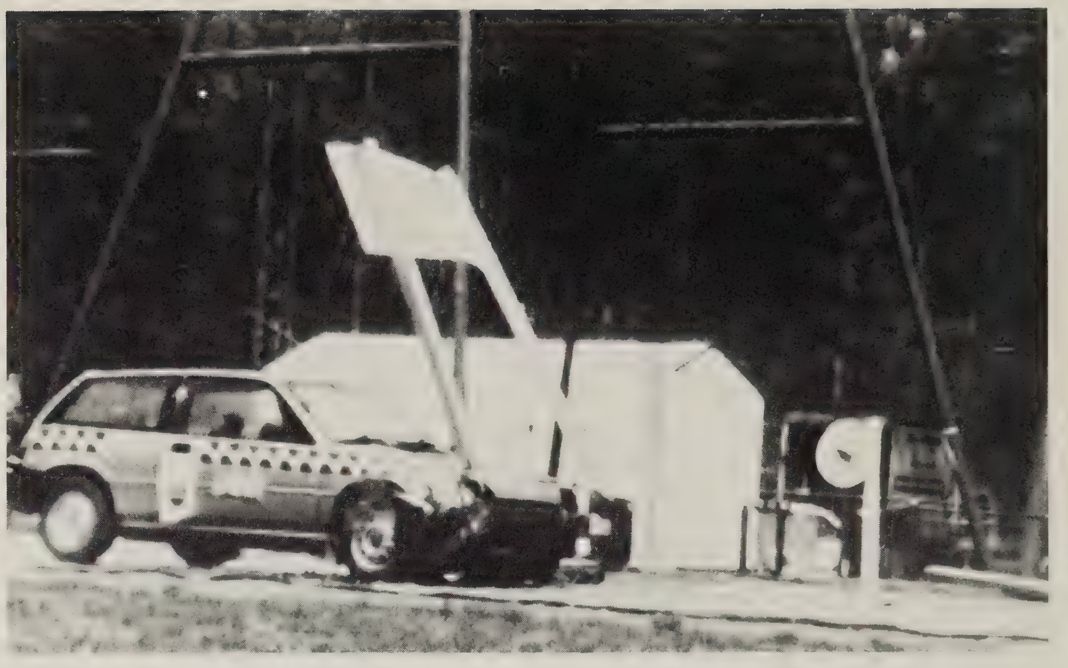
This publication may only be purchased from the NTIS. (PB No. 91-104422/AS, Price code: A04.)

Impact Tests of Luminaire Supports with the 1800-lb Pendulum, Publication No. FHWA-RD-90-064

by Design Concepts Research Division

This report contains the results of crash tests performed with the 1800-lb (817-kg) pendulum on slipbase and anchor base luminaire supports. It also has the results of tests performed on a breakaway sweeper plate attached to the underside of the pendulum body to more accurately represent the undercarriage of an automobile. The test were conducted at 20 mi/h (8.94 m/s).

This publication may only be purchased from the NTIS. (PB No. 91-108076/AS, Price code: A03.)



Torque Sensitivity and Other Transformer Base Testing, Publication No. FHWA-RD-89-131

by Design Concepts Research Division

This report contains the results of additional transformer base testing performed during the validation phase of the FOIL bogie. Included are tests to determine the optimal torque for fastening the transformer base to its foundation, examine the reaction of the bogie's nose at 40 mi/h (17.88 m/s) and reduce levels on the bogie's structure through an alternative honeycomb configuration.

This publication may only be purchased from the NTIS. (PB No. 91-104414/AS, Price code: A04.)

AC Stripping Problems and Corrective Treatments, Publication No. FHWA-RD-90-049

by Pavements Division

This study was conducted to determine the most effective method of introducing lime into asphalt concrete mixtures, to improve the reliability of laboratory test methods used to identify moisture-susceptible asphalt-aggregate combinations, and to evaluate the effectiveness of experimental construction projects from selected highway sections in four States.

Although the addition of lime through wet methods resulted in higher strengths than dry methods, the difference was not statistically significant to support a conclusion that wet methods are better than dry methods.

This publication may only be purchased from the NTIS. (PB No. 91-104924/AS, Price code: A09.)

New Research

The following new research studies reported by the FHWA's Office of Research and Development are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description:

- FHWA Staff and Administrative Contract Research contact *Public Roads*.
- Highway Planning and Research (HP&R) contact the performing State highway or transportation department.
- National Cooperative Highway Research Program (NCHRP) contact the Program Director, NCHRP, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC 20418.
- Strategic Highway Research Program (SHRP) contact the SHRP, 818 Connecticut Avenue, NW, 4th floor, Washington, DC 20006.

NCP Category A—Highway Safety

A.1: Traffic Control for Safety

Title: Potential Safety Applications of Advanced Technology (NCP No. 3A1C0152)

Objective: Identify highway safety problems that can be addressed by in-vehicle or exterior technology. Match existing technologies with safety problems. Where technologies do not exist, specify needed functional requirements.

Performing Organization: University of Michigan, Ann Arbor, MI 48109

Expected Completion Date: March 1992

Estimated Cost: $213,000 (FHWA Administrative Contract)

A.4: Special Highway Users

Title: Study Design for Car/Truck Passing Sight Requirements (NCP No. 3A4A3233)

Objective: To identify discrepancies and inconsistencies in the design and marking of no-passing zones. Develop detailed experimental plans to be executed under future contracts that address the issues and inconsistencies. Consider driver/vehicle capabilities and alternative passing methods such as the use of passing lanes.

Performing Organization: McGee Incorporated, Vienna, Virginia 22182

Expected Completion Date: November 1991

Estimated Cost: $67,000 (FHWA Administrative Contract)

Title: Safety Impacts of Different Speed Limits for Cars and Trucks (NCP No. 3A4A282)

Objective: Examine effects of using lower freeway speed limits for trucks on highway safety, traffic, truck operations, and costs. Examine truck speed and accident data in States with and without dual speed limits. Use the results to either add or remove dual limits.

Performing Organization: Scientex Corporation, Washington, DC 20006

Expected Completion Date: June 1993

Estimated Cost: $209,000 (FHWA Administrative Contract)

NCP Category C—Pavements

C.2: Evaluation of Flexible Pavements

Title: Resilient Modulus of Tennessee Subgrades (NCP No. 4C2B1342)

Objective: Determine the resilient modulus of Tennessee subgrade soils for pavement design. Develop a data base for various Tennessee soils, create a statistical model, and develop an alternative to the current repeated load test.

Performing Organization: University of Tennessee, Knoxville, TN 37996

Funding Agency: Tennessee Department of Transportation

Expected Completion Date: September 1992

Estimated Cost: $150,000 (HP&R)

C.4: Pavement Management Strategies

Title: Dynamic Vehicle Forces on Pavements (NCP No. 3CA2162)

Objective: Use newly developed dynamic truck model to identify truck suspension-wheel-tire systems with significant potential for pavement damage. Measure forces generated by different axle suspension systems and various tire types and pressures in the laboratory.

Performing Organization: Pennsylvania Transportation Institute, University Park, PA 16802

Estimated Cost: $200,000 (FHWA Administrative Contract)

NCP Category D—Structures

D.2: Bridge Management

Title: Guidelines for Permitting Overloads (NCP No. 4D2B2042)

Objective: To develop the necessary elements for conducting a fast, first-level evaluation of overload requests. The work plan includes a literature review, structural analysis and rating of sample bridges, and a final report.

Performing Organization: Purdue University, West Lafayette, IN 46204

Funding Agency: Ohio Department of Transportation

Expected Completion Date: March 1993

Estimated Cost: $134,067 (HP&R)

NCP Category E—Materials and Operations

E.3: Geotechnology

Title: Sealing Geotechnical Exploratory Holes to Protect the Subsurface Environment (NCP No. 5E3B0762)

Objective: Determine economical and effective seals for small diameter boreholes to prevent groundwater contamination. Suggest methods to verify that the seals have been properly constructed.

Performing Organization: University of Massachusetts, Amherst, MA 01003

Expected Completion Date: January 1994

Estimated Cost: $300,000 (NCHRP)

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