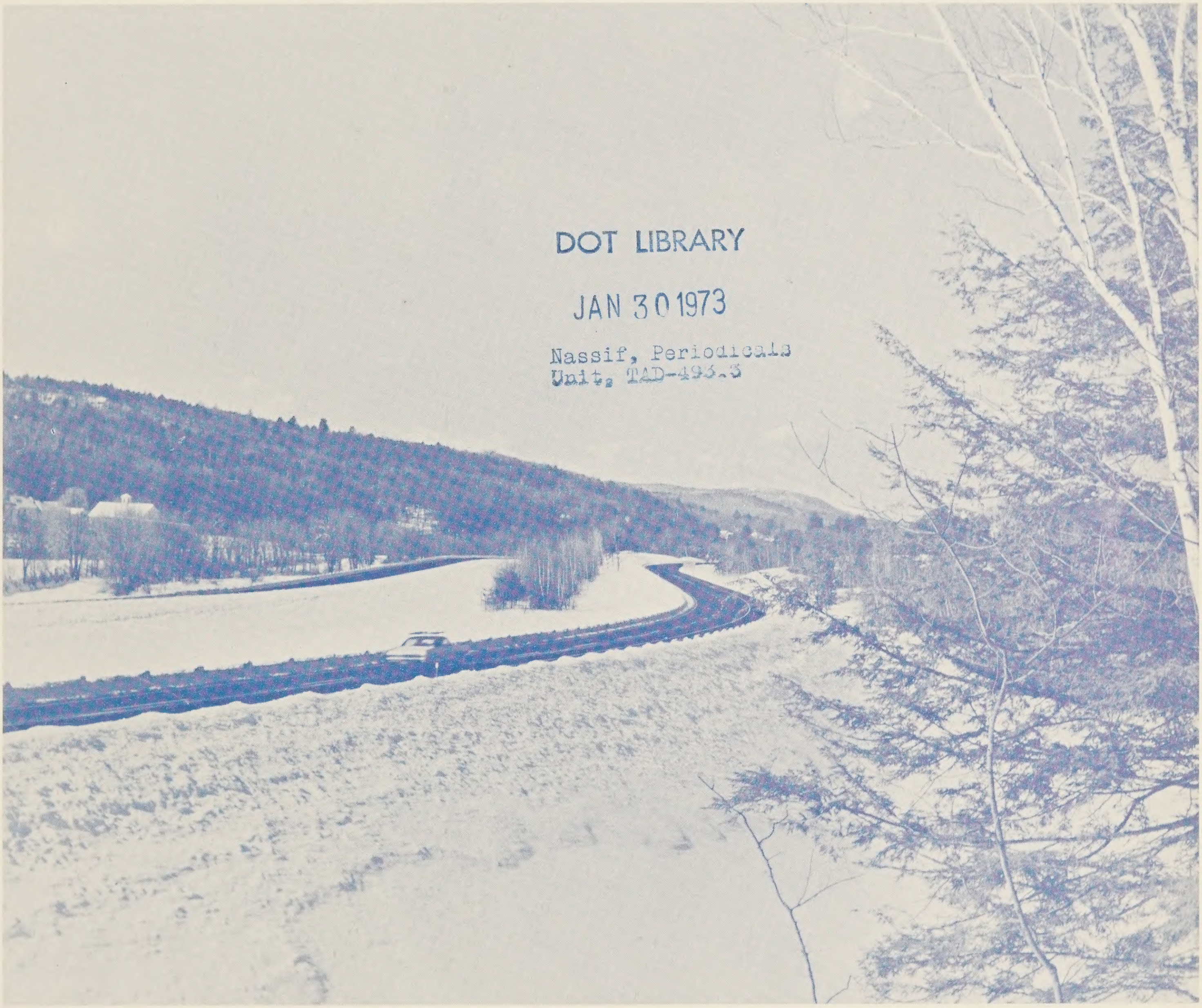
Vol. 37/No. 3

December 1972

Public Roads

A JOURNAL OF HIGHWAY RESEARCH



U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

Published Quarterly by the Associate Administrator for Research and Development
G. W. Cleven, Associate Administrator
Fran Faulkner, Editor
December 1972/Vol. 37, No. 3

U.S. DEPARTMENT OF TRANSPORTATION
JOHN A. VOLPE, Secretary

FEDERAL HIGHWAY ADMINISTRATION
R. R. BARTELSMEYER, Acting Administrator

CONTENTS

Articles

Departments

COVER

I–89 northwest of Concord. (Photo courtesy of New Hampshire Department of Public Works and Highways.)

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
Washington, D.C. 20590

FHWA REGIONAL OFFICES

No. 1. 4 Normanskill Blvd., Delmar, N.Y. 12054.
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Puerto Rico.

No. 3. 1633 Federal Building, 31 Hopkins Plaza, Baltimore, Md. 21201.
Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia.

No. 4. Suite 200, 1720 Peachtree Rd., N.W., Atlanta, Ga. 30309.
Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee.

No. 5. 18209 Dixie Highway, Homewood, Ill. 60430.
Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin.

No. 6. 819 Taylor St., Forth Worth, Tex. 76102.
Arkansas, Louisiana, New Mexico, Oklahoma, and Texas.

No. 7. 6301 Rockhill Rd., Kansas City, Mo. 64131.
Iowa, Kansas, Missouri, and Nebraska.

No. 8. Denver Federal Center, Building 40, Denver, Colo. 80225.
Colorado, Montana, 'North Dakota, South Dakota, Utah, and Wyoming.

No. 9. 450 Golden Gate Ave., Box 36096, San Francisco, Calif. 94102.
Arizona, California, Hawaii, and Nevada.

No. 10. 412 Mohawk Building, 222 S.W. Morrison St., Portland, Oreg. 97204.
Alaska, Idaho, Oregon, and Washington.

No. 15. 1000 North Glebe Rd., Arlington, Va. 22201.
Eastern Federal Highway Projects.

No. 19. Drawer J, Balboa Heights, Canal Zone.
Inter-American Highway: Colombia, Costa Rica, Nicaragua, and Panama.

Public Roads, A Journal of Highway Research, is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, at 4.50 per year ($1.25 additional for foreign mailing) or $1.25 per single copy. Subscriptions are available for 1-, 2-, or 3-year periods. Free distribution is limited to public officials actually engaged in planning or constructing highways and to instructors of highway engineering. There are no vacancies in the free list at present.

Use of funds for printing this publication has been approved by the Office of Management and Budget, March 23, 1971.

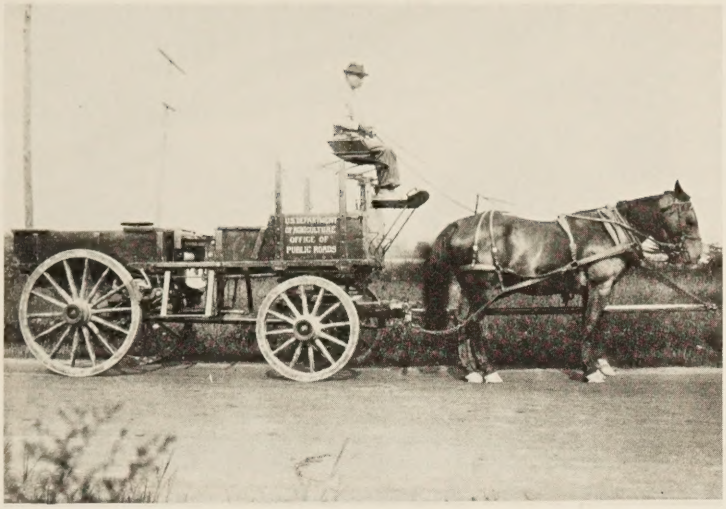


Figure 1.—Early skid measurement system (about 1905).

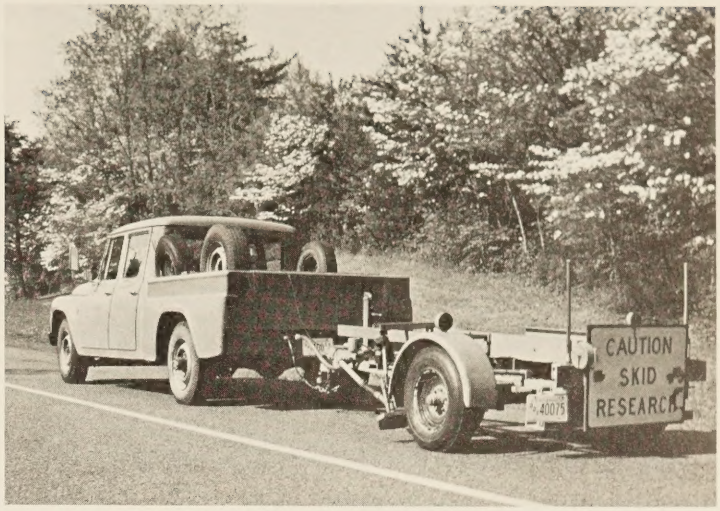


Figure 2.—Modern skid measurement system.

A National Program To Standardize Skid Resistance Measurements

Reported by JOHN R. WATSON, Jr., and LARRY M. COOK, Highway Engineers, Implementation Division

OFFICE OF DEVELOPMENT

Introduction

MEASURING pavement skid resistance is by no means a new idea. When paved highways were few and automobiles scarce, highway engineers were measuring pavement skid resistance. Early techniques, by today's standards, lacked sophistication. The measuring systems were of the *real* horsepower (fig. 1) rather than the mechanical variety (fig. 2). But yesterday's engineers, much the same as today's, had one major goal—improve highway safety.

More than half a century after the nation began paving its roads, highway safety is still a complex problem, involving many facets of the nation's highway system. Although skid resistance characteristics of pavements are but one problem, they are still one of the more important safety variables in today's world of high-speed highways.

Even though it is difficult to isolate accidents where slippery pavements are the sole or major cause, it is known that pavements have a lower skid resistance when they are wet. Further, accident rates increase when pavements are wet. Thus, increasing the skid resistance of pavements is one way to reduce the frequency and severity of accidents.

Slippery pavements, of course, must be identified before the condition can be corrected. Historically, a number of highway agencies relied on accident records to indicate the location of such pavements. But this has meant that damages, injuries and fatalities must occur before the hazard becomes known and corrective action taken.

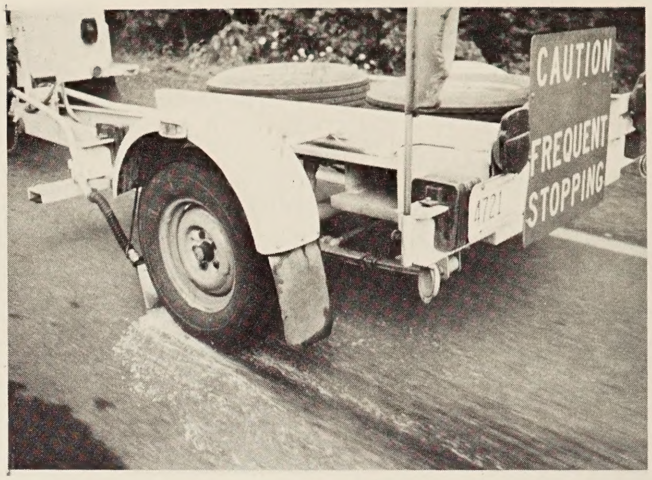
One way to correct this problem is to resurface highways so often that they never have a chance to become slippery. Another solution is to inventory the level of skid resistance on all pavements and schedule corrective action before they become inadequate for the needs of the public. A third solution is to include skid resistance as a design parameter for new construction.

Measuring Skid Resistance

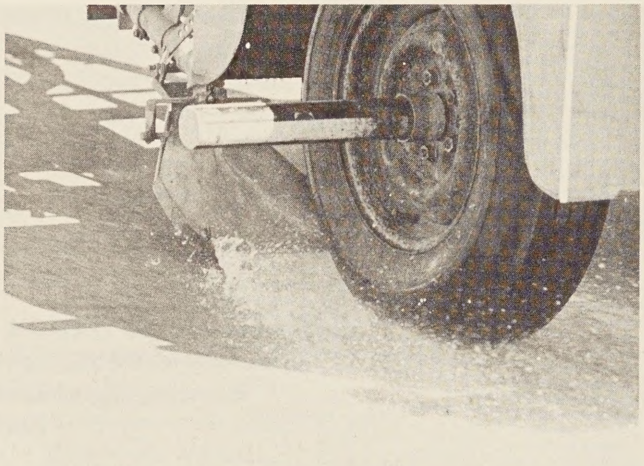
Currently, the majority of State highway departments measure pavement skid resistance with locked-wheel skid measurement systems, which are reported to be in substantial compliance with the requirements of ASTM Designation E 274-70, "Standard Method of Test for Skid Resistance of Paved Surfaces Using a Full-Scale Tire." This, however, is not sufficient guarantee of repeatable test results by any one measurement system, or good correlation between different measurement systems (*1*).[1]

[1] Italic numbers in parentheses refer to the references listed on page 80.

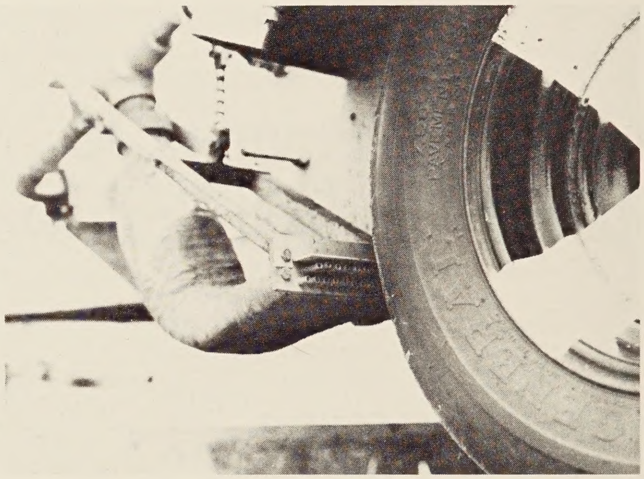
A—Brush.



B—Divergent flow.



C—Parallel flow.



D—Multitube.

Figure 3.—Water nozzles in current use.

Achieving reliable and repeatable results with any complex measuring device is difficult, for the many components contribute to uncertainties in the measured quantity. The acceptable degree of inaccuracy, or error, is usually a compromise between the desired accuracy and the effort to improve the measurement process. In the past, the error in skid testing clearly has been too large. The problem, therefore, has been to determine the sources of errors and to find means of reducing them (*1*).

The equipment and procedures are part of the skid measurement process which includes the following:

- Skid measurement system
- Driver and operator
- Equipment operating procedures
- Field testing procedures
- Calibration equipment
- Calibration procedures
- Interpretation of test results
- Reporting test results

The subsystems of each skid measurement system have an influence on the accuracy and precision of the measurement process. An example of such a subsystem is the method of water application. Figure 3 shows four of the many methods currently used for applying water in front of the skid test tire. Each of these water nozzles is purported by its developers to meet the requirements of the current method of test, ASTM E 274-70. This standard method of test prescribes that a given amount of water be uniformly distributed in front of the test tire. It has been shown, however, that the different water dispersement patterns of these nozzles significantly affect the test results on a given highway pavement.

This illustration identifies only one of the many sources of errors in measuring skid resistance. In addition to equipment, errors can be traced to other sources within the measurement process which significantly influence test results. Some of these sources, such as the field testing procedures, can be controlled within limits. Others, like weather and pavement condition, are relatively uncontrollable. Even so, their effects must be recognized and accounted for in some manner to achieve reliability and repeatability in measurement.

Standardization of measuring process

In order to achieve reliability, it is necessary to standardize the entire process of measuring skid resistance. This involves evaluating all known sources of errors and controlling or compensating for those which are significant. With the process standardized, skid test measurements across the nation will be compatible and comparable.

The measurement process is evaluated in terms of two basic performance criteria: accuracy and precision. Accuracy (reliability) concerns the deviation of measurements from an accepted reference level or value for the property of the reference material being measured. In other words, accuracy is the agreement between a measured value and the reference level (*2*).

The term "accepted reference level" refers to a value or values of the measurement that might be found in any given portion of material by a controlled measurement process based on an authorized and accepted test method—the actual or hypothetical measurement yielded by a suitable standard method (*2*).

Precision (repeatability) concerns the spread between the individual measurement in the measurement process. It is the degree of agreement among a series of measurements when expressed in terms of the standard deviation of a variable; the smaller the standard deviation, the higher the precision (*3*). These performance criteria can be used to describe a skid measurement system as a whole or any subsystem thereof.

One way of illustrating the use of these terms is by the example of a marksman shooting at a target. If all the shots are neatly grouped inside the bull's-eye (fig. 4A), there is both good precision and good accuracy. If the shots are widely scattered on the target, but are well distributed around the bull's-eye (fig. 4B), there is good accuracy (average of shots being close to the bull's-eye) but poor precision. Finally, if the shots are spaced closely together near one spot some distance from the bull's-eye (fig. 4C), there is good precision but poor accuracy. The distance from the bull's-eye to the center of the group represents bias (*4*).

Federal Highway Administration (FHWA) standardization program

For the past 2 years, FHWA has been developing a program to standardize the measurement of pavement skid resistance. This program is specifically designed to aid State highway departments and other transportation agencies in conducting the skid resistance inventories needed for their highway safety programs. It provides for the establishment of national and area reference skid measurement systems and development of evaluation and calibration procedures. Evaluation and calibration services are provided for the inventory skid measurement systems and skid measurement processes

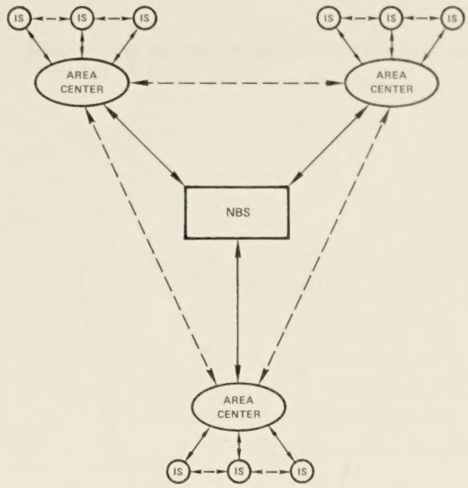


Figure 5.—Relationship among measurement systems.

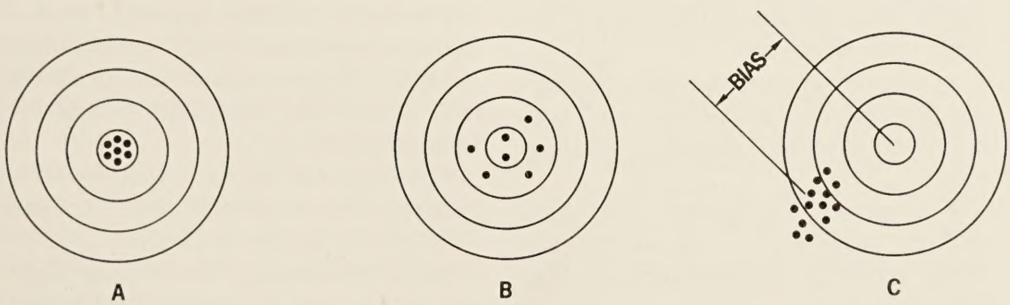
IS represents inventory skid measurement systems for States and other agencies.

of State highway departments and other agencies.

At the national level, the FHWA program provides for an interim national reference skid measurement system which will be maintained and operated by the National Bureau of Standards. (NBS). The NBS will also develop procedures for evaluating and calibrating the area reference skid measurement systems and furnish evaluation and calibration services for these systems. The interim national reference system will be the authorized and accepted skid measurement system used to establish the "accepted reference level" (*2*) to which the area reference system and inventory system shall relate.

Eventually, all measurement systems will be systematically related to the National Measurement System (NMS).

The NMS consists of two basically different but interacting systems: conceptual and operational. The conceptual system—providing the fundamental basis for building the operational system —"is a rational, ordered structure of rules, definitions, laws, conventions, or procedures." The operational system consists of a structured organization of people interacting under central guidance to perform a function (*5*). Compatible measurements through the NMS are achieved by a hierarchy of comparisons, or calibrations, at ever increasing levels of accuracy until, for each quantity, all measurements are referred to a common tie point or standard (fig. 5). This structured



Good accuracy and good precision equal exactness (average on center).

Good accuracy but poor precision (average on center).

Good precision but poor accuracy (average off center).

Figure 4.—Example of accuracy and precision statements.

Figure 6.—Service areas for FHWA field test and evaluation centers.

system of comparisons illustrates the basic principle of NMS—that "things equal to the same thing are equal to each other." (*5*).

At the area level, the FWHA has established three field test and evaluation centers (area center) at strategic locations across the nation to provide standardization services to State highway departments and other agencies. These centers will be operated by the Ford Motor Company at its Arizona Proving Ground, Yucca, Ariz.; the Texas Transportation Institute at its Research Annex near College Station, Tex.; and the Ohio State University at the Ohio Highway Transportation Research Center near East Liberty, Ohio. Figure 6 shows the approximate location and initial service areas of these centers (*6*).

Each center will have an area reference skid measurement system that has been evaluated and calibrated against the national reference system. The area reference systems will be used to establish a relationship between the national reference system and the inventory system; i.e., the established accuracy of the inventory system. The centers will also have the necessary facilities for static and dynamic calibration of skid measurement systems, evaluation of the skid measurement process, and technical assistance on the measurement of pavement skid resistance.

Accurate and precise measurements of pavement skid resistance nationwide will be a reality after full development and implementation of the standardization and calibration services. At that time, it is planned that an FWHA operating office will assume the responsibility for carrying on the standardization program.

Federally coordinated program of research and development

Additional efforts toward standardization of skid measurements are being accomplished through a series of studies supported by FHWA administrative contract funds, Federal-aid Highway Planning and Research funds, and Federal-aid National Cooperative Highway Research Program funds (*7*). Studies are being directed toward:

- Determining how specific equipment components, test procedures, and environmental factors influence measurements;
- Developing equipment components and test procedures to improve the precision, reliability, and usefulness of measurements;
- Developing a capacity in State highway departments to conduct operational surveys of pavement surface properties;
- Developing better ways to inventory skid resistance of pavement surfaces.

Other current research and development efforts will make it possible to specify the optimum combination of frictional characteristics of pavement surfaces, traffic control devices and other highway characteristics for a wide variety of situations involving potential skid accidents. Providing antiskid pavements, surface drainage systems and other measures needed to effectively reduce skid accidents will be possible without excessive costs, undue tire wear, or bothersome noise.

Benefits

Potentially, the annual savings from reducing skid accidents is about one billion dollars (*7*). This estimate is based on annual costs of 16 billion dollars for all accidents, of which about 20 percent occur in wet weather; of these, about one-third involve skidding. A successful national skid accident reduction program will effectively improve this element of highway safety by substantially reducing the frequency and severity of wet weather skidding accidents. Most important, however, is the fact that annual savings not only can be measured in money, but also in lives saved.

REFERENCES

(*1*) "Research Results Digest," *NCHRP,* Report No. 38, April 1972.

(*2*) "Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material," *ASTM,* Specification E-177, Part 30, 1970.

(*3*) "Preparing Precision Statements for Test Methods for Construction Materials," *ASTM,* Specification C-670, Part 10, 1971.

(*4*) Hudson, S. B., "Handbook of Applications of Statistical Concepts to the Highway Construction Industry, Part I—Initial Computations and Applications," *Materials Research and Development, Inc.,* Report MAT-RES-DEV-WGAI-71-660-1, June 1971.

(*5*) Huntoon, R. D., "Concept of a National Measurement System," *Science,* Vol. 158, p. 68, Oct. 6, 1967.

(*6*) Ivey, Don L., "The Federal Highway Administration's Pilot Field Test and Evaluation Center," *Texas Transportation Institute,* Texas A&M University, March 1972.

(*7*) "Conference on Skid Resistance Surface Courses," *Sacramento, Calif.,* Conference Proceedings, Report No. FHWA-RDDP-10-3, June 1972.

Overtaking and Passing Vehicle Accidents

Reported by WILLARD J. KEMPER,
Civil Engineering Technician,
PHYLLIS E. HUNTINGTON,
Mathematical Statistician, and
STANLEY R. BYINGTON,
Highway Research Engineer,
Traffic Systems Division

OFFICE OF RESEARCH

The research reported here shows that 43 percent of all traffic accidents on rural two-lane highways involve overtaking and passing maneuvers. Of these, slightly more than half (23 percent of the total) involved an overtaking maneuver (where a vehicle comes up behind a slower moving lead vehicle) and 20 percent of the total involved a passing maneuver (where the following vehicle goes around the slower moving vehicle).

Also presented are detailed analyses of overtaking and passing accidents by location (between and at intersections/driveways) and severity (extent of injury, property damage, and cost per vehicle-mile). Potential accident cost savings for possible overtaking and passing remedial driver-aids are also presented.

Introduction

IN 1965 the Bureau of Public Roads (now Federal Highway Administration) initiated an overtaking and passing project to undertake needed research leading to development of systems for aiding drivers in solving discrimination, judgment, and vehicle control problems during driving maneuvers on two-lane rural highways. The need for the research and development effort was based in part on the following facts:

• During 1963, millions of accidents involving 31,000 fatalities and 680,000 injuries occurred on the 3.1 million miles of rural highways in the United States (*1*, *2*).[1] About 70 percent of all fatalities take place on rural highways. Specific national data on motor-vehicle accidents —fatal, injury, and property damage— are not available for two-lane rural highways only.

• Of all rural accidents reported in 1963, approximately 35 percent involved nonintersection collisions between two or more motor vehicles. Another 23 percent involved multiple-vehicle intersection collisions (*3*). Such multiple-vehicle collisions both between and at intersections obviously involved one of the following maneuvers by drivers: overtaking, following, or passing another vehicle.

As research proceeded, more refined accident data were needed for economic evaluations of proposed remedial driver-aid systems including an electronic overtaking and passing information system. The objective of this study, therefore, is to provide better estimates of the number of overtaking and passing accidents which could possibly be avoided through implementation of the electronic overtaking and passing information system. It is preliminary in nature and is supplemented by a study entitled, "Identification and Evaluation of Remedial Aid Systems for Passing Maneuvers on Two-Lane Rural Roads" (*4*).

To meet the study objective, reports of accidents that occurred in 1966 on 35 miles of two-lane rural highway in Virginia were studied to ascertain the percentages that could be attributed to overtaking and passing maneuvers. This was done by analyzing accident descriptions rather than by relying on coded entries.

Definitions

As used in this study, overtaking and passing accidents are those accidents which occur in conjunction with one of the following vehicle actions or maneuvers:

Overtaking: A vehicle following another vehicle in the same lane is overtaking the vehicle ahead when it is moving faster than the lead vehicle; i.e., when the distance between the lead vehicle and the following vehicle decreases with time.

Passing: A vehicle is in the act of passing when it pulls out of the lane behind the lead vehicle and into the adjacent lane, comes abreast of the leading vehicle and returns to the original lane of travel in front of the passed vehicle.

[1] Italic numbers in parentheses identify the references listed on p. 88.

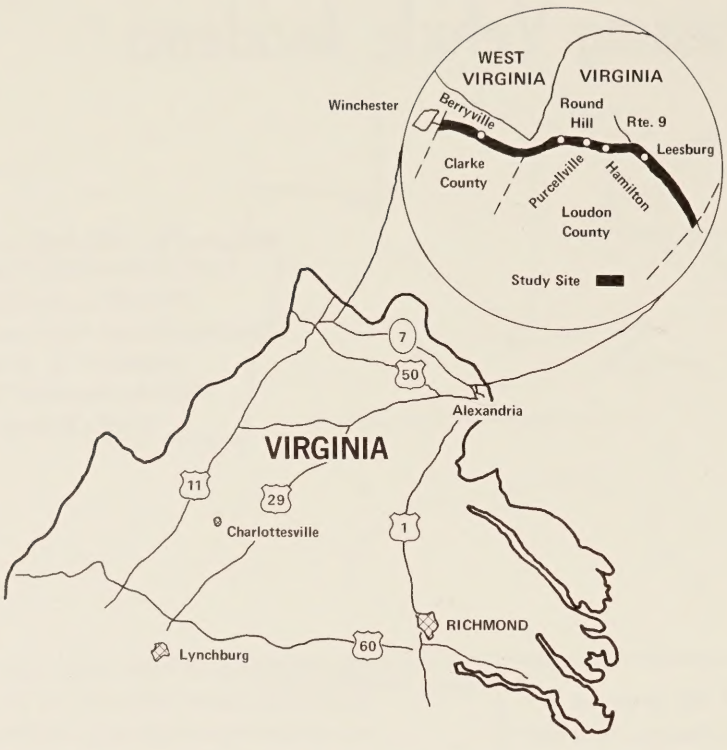


Figure 1.—Study test site.

Study Site

Preliminary cost effectiveness analyses of an electronic passing aid system showed the system to be practical where the average daily traffic (ADT) is in excess of 2,000 vehicles per day and the terrain is either rolling or mountainous (*5*). Based on these criteria and the desire to have ready access to a study site and to records of accidents occurring thereon, a segment of Virginia Route 7, shown in figure 1, was selected as the study site. This site is in rolling and mountainous terrain. At the time of the study, this two-lane bituminous road was 24 feet wide. All shoulders were unpaved and ranged in width from 4 to 6 feet in Clarke County to 8 to 10 feet in Loudoun County (fig. 1). The speed limit along the site was 55 m.p.h., except in towns where it was either 25 or 35 m.p.h.

Although the highway segment is about 43 miles long, exclusion of Leesburg, Hamilton, Purcellville, Round Hill, and Berryville reduced the study site length to about 36 miles. Roadway mileage in these towns and associated accidents were not included in the study because the proposed electronic passing-aid system is intended for use only in rural nondeveloped areas.

Accident reports for the site were obtained from the Virginia Division of Motor Vehicles in Richmond, Va.

Data describing the sections of State Route 7 to which the accident data of this study apply are shown in table 1.

Accident Data

For this study, data for accidents occurring on the study site for only 1 year, 1966, were obtained from accident reports furnished by Virginia's Division of Motor Vehicles. Eighty-four percent of the accident reports had been completed by law enforcement officers and the remainder by the accident-involved drivers. Reports were not duplicated by both law enforcement officers and accident-involved drivers.

In these reports, accidents were classified according to driver actions immediately prior to the accident. This classification contained six categories that might be associated with an overtaking or passing maneuver: (1) Overtaking on hill, (2) overtaking on curve, (3) overtaking at intersection, (4) improper passing of school bus, (5) cutting in, and (6) other improper passing. This classification technique was not considered in this analysis because of uncertainties surrounding use of the various categories and situations like the following:

> Vehicle No. 1 was going east on Route 7. A westbound vehicle was passing a line of cars and No. 1 ran off the right side of the road in order to avoid a collision. No. 1 then skidded back across the road and struck vehicle No. 2 in the left front. (7)

On the accident report form for the above accident, boxes under the heading of "Driver Actions Indicated" and "What Drivers Were Doing" were respectively checked as *No Violations* and *Going Straight Ahead*. Thus, no hint was given that the accident resulted from a passing maneuver except within the description of the accident. Accordingly, each accident used in this study was classified as an overtaking, passing, or other type accident based on the earlier definitions of the applicable maneuver and using only the diagram and descriptive portions of that part of the report form. The effect of employing these portions of the form for classifying *overtaking* and *passing* accidents, rather than check marks under "Driving Action Indicated" and "What Drivers Were Doing," is analyzed in the next section.

Accident Analysis

The sample for this study included 182 accidents. Using the above described methodology, 36 (20 percent) of the accidents were attributed to errors in executing the passing maneuver and 42 (23 percent) to errors in executing the overtaking maneuver. Figure 2 shows the distribution of these accidents in the total

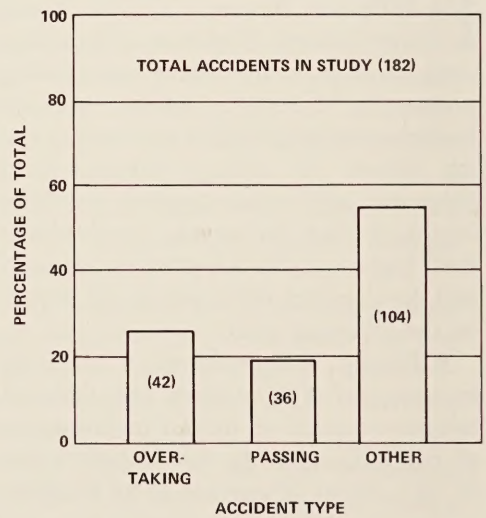


Figure 2.—Distribution of overtaking, passing and other accidents in sample.

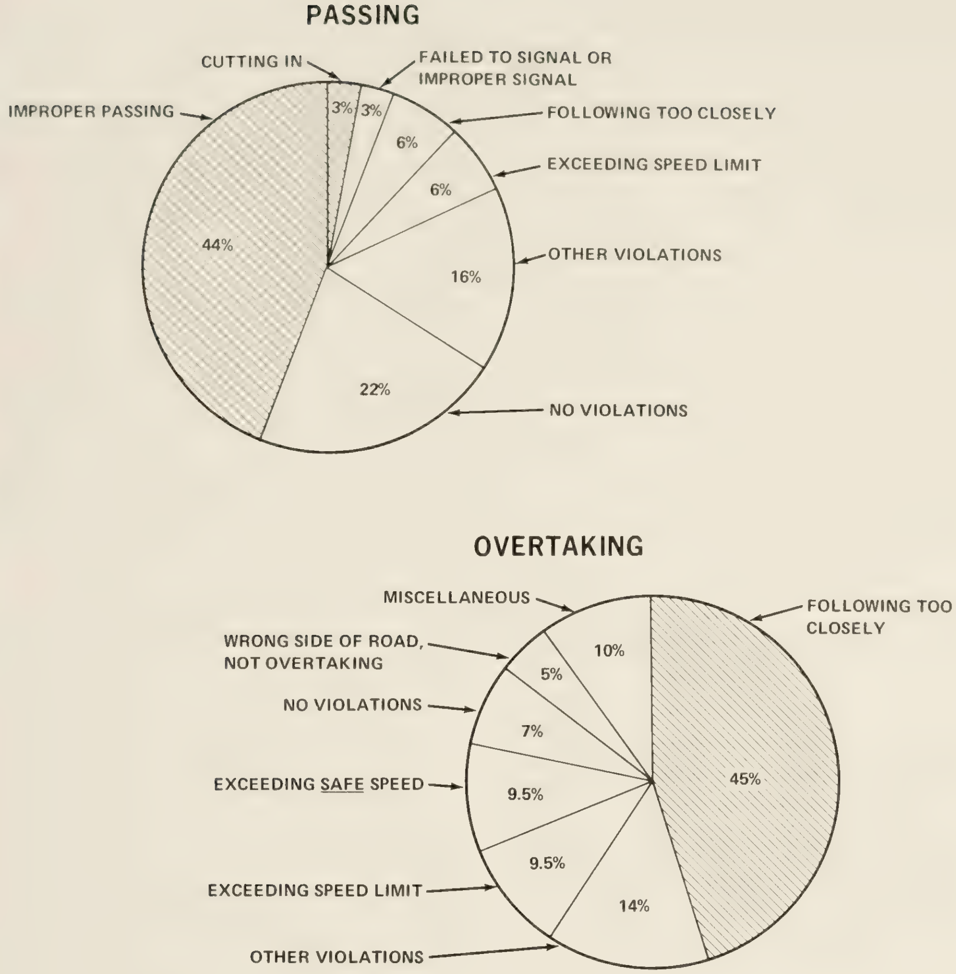


Figure 3.—Driver actions in overtaking and passing accidents.

(Shaded area: Normally associated with passing or overtaking accidents.)

sample of accidents studied. Had accidents been classified through use of the "Drivers' Actions Indicated" section on the accident report forms, only 16 of the 36 passing accidents (44 percent) and 19 of the 42 overtaking accidents (45 percent) would have been so classified. Similarly, only 29 passing and 18 overtaking accidents would have been identified through use of the "What Drivers Were Doing" section of the accident report forms.

Figures 3 and 4 summarize the "Drivers' Actions Indicated" and "What Drivers Were Doing," classifications respectively, for the properly classified 36 overtaking and 42 passing accidents. Shaded portions of the pie charts in the two figures depict those classification elements that appear to be associated with overtaking and passing accidents. The inadequacy of these two classification schemes in determining the number of overtaking and passing accidents is illustrated by noting that:

(1) "Following too Closely" usually relates more to a car-following situation than to an overtaking maneuver.

(2) "Following too Closely," "Exceeding Speed Limit," "Other Violations," all codes under "Drivers' Actions Indicated," appear in both overtaking and passing accident reports.

(3) Under "Drivers' Action Indicated" on the accident report forms, there are only three codes specifically related to overtaking: "Overtaking on Hill," "Overtaking on Curve," and "Overtaking at Intersection." Yet, on only one of the 36 overtaking accident report forms had any of these codes been checked.

(4) "Going Straight Ahead" and making various turns (left, right or U), all elements under "What Drivers Were Doing," appear in both overtaking and passing accident report forms.

Tables 2 and 3, respectively, list the types of situations resulting from overtaking errors and passing errors. A description of the types of collision or noncollision accidents resulting from such errors are shown explicitly for the purpose of clarification. Reference was made to the definitions of the overtaking and passing maneuvers to determine in which category each particular occurrence

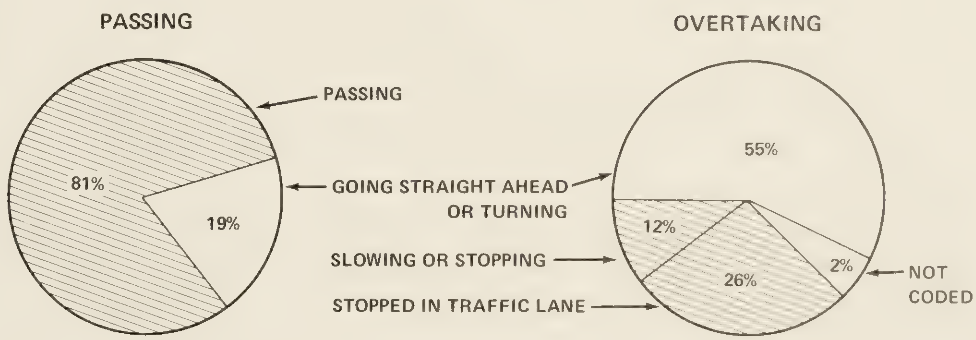


Figure 4.—What drivers were doing in overtaking and passing accidents.

(Shaded area: Normally associated with passing or overtaking accidents.)

Table 1.—Test site sections and accidents for calendar year 1966 *(6)*

Section No.	Section From	Section To	Length (miles)	Average daily traffic	Annual vehicle miles (millions)	Accidents	Accident rate (per 100 MVM)
1	Fairfax [1]	Leesburg [2]	11.22	6,485	26.6	77	290
2	Leesburg [3]	Route 9	2.14	6,795	5.3	7	132
3	Route 9	Hamilton [2]	2.61	5,525	5.3	23	437
4	Hamilton [3]	Purcellville	1.09	5,525	2.2	10	455
5	Purcellville [3]	Round Hill [2]	1.82	5,045	3.4	9	269
6	Round Hill [3]	Clarke [1]	4.33	3,005	4.7	16	337
7	Loudoun [1]	Berryville [2]	7.51	2,560	7.0	22	314
8	Berryville [3]	Frederick [1]	4.93	5,760	10.4	26	251
	Total		35.65		64.9	[4] 190	293

[1] County line.
[2] East city or town limits.
[3] West city or town limits.
[4] Of the 190 accidents, eight occurred on sideroads and were eliminated from further analysis in the study leaving a study sample of 182 accidents.

section and driveway accidents shown in table 5 occurred at the 63 intersections and 451 driveways along the study site.

As would be expected, a high proportion of passing accidents (72 percent) occurred at locations remote from either intersections or driveways. Surprisingly, however, the high percentage of (1) overtaking accidents (50 percent) occurred between intersections and driveways where there are fewer stopping maneuvers, and (2) passing accidents (11 percent) occurred at intersections, where passing is normally prohibited. Therefore, there appears to be a need to assist drivers in overtaking and passing maneuvers along all portions of two-lane rural highways.

should be placed. All percentages shown are based on the total number (182) of accident reports reviewed.

For comparative inspection of those accidents which were not included in the overtaking or passing sample, table 4 shows the types of accidents represented by the remaining 104 accidents. The largest proportion of "Other Accidents" involved only a single vehicle. Of the 39 accidents classified as "Single Vehicle (no other vehicle involved in any way)," 13 were judged from comments or codes on the accident report forms to have been caused by drivers exceeding a safe speed (or speed limit), 10 from vehicles skidding on a wet pavement, and five from vehicles striking a soft shoulder. The remaining 11 accidents resulted from miscellaneous causes including drunken driving, falling asleep, and tire and brake failures.

Location

In view of the objective of the Overtaking and Passing Project; i.e., to develop systems for aiding drivers in solving discrimination, judgment, and vehicle control problems in driving maneuvers on two-lane rural highways, the question of the most likely locations which would be prime candidates for placement of a remedial system was investigated. Table 5 shows a breakdown of the sampled overtaking and passing accidents occurring at intersections, driveways, and between intersections. The percentages shown were computed in terms of the number of accidents in the separate overtaking or passing categories. The inter-

Table 2.—Percentages of accidents resulting from overtaking maneuvers

Accident type	Accidents	Total sample
	Number	*Percent*
Rear-end collision with moving vehicle	10	5.5
Rear-end collision with stopped vehicle in roadway	19	10.5
Rear-end collision with turning vehicle	2	1.1
Collision with another vehicle to avoid rear-end collision	4	2.2
Single vehicle overturned to avoid rear-end collision	1	0.5
Single vehicle ran off roadway to avoid rear-end collision	6	3.3
Total	42	23.1

Table 3.—Percentages of accidents resulting from passing maneuvers

Accident type	Accidents	Total sample
	Number	*Percent*
Head-on collision while passing	1	0.5
Sideswipe while passing	7	3.8
Forced off roadway by vehicle in same direction (either vehicle in act of passing)	6	3.3
Forced off roadway by oncoming passing vehicle	1	0.5
Ran off roadway while attempting or completing pass	6	3.3
Collision to avoid head-on collision	2	1.1
Mechanical failures while attempting pass	2	1.1
Collision while passing left turning vehicle	9	4.9
Rear-end collision while attempting to pass	2	1.1
Total	36	19.6

Table 4.—Percentages of nonovertaking and nonpassing accidents by collision type

Accident type	Accidents	Total sample
	Number	*Percent*
Single vehicle (no other vehicle involved in any way)	39	21.5
Single vehicle (forced off road by another vehicle)	4	2.2
Angle collision at intersection or driveway	15	8.2
Opposite direction collision—no passing involved	20	11.0
Left turn across opposite lane	7	3.8
Collision with animal (deer, cow or dog)	16	8.8
Other (including collision with pedestrian, bicycle, etc.)	3	1.6
Total	104	57.1

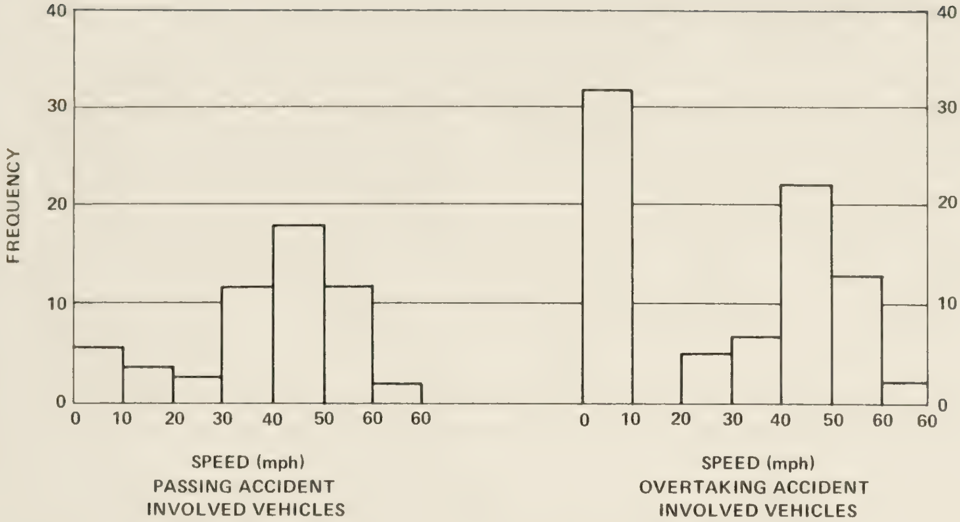


Figure 5.—Estimated speeds of all involved vehicles just prior to each accident.

Injuries

No fatalities resulted from any of the overtaking or passing accidents reviewed in this sample. This is unusual when considering the distribution of involved drivers' estimated speeds just before each accident, as recorded on the accident reports. Figure 5 shows the distribution for each type of accident. In over 40 percent of each accident type, the estimated speed of travel just prior to the accident was in excess of 40 m.p.h. Further, in many of the overtaking accidents, the speed differential between involved vehicles, based on estimated speeds, was in excess of 20 m.p.h. Still, based on the normal ratio of fatal accidents to property damage and injury accidents for head-on and rear-end collisions on rural highways (1 to 142) (*8*), the absence of a fatality in this study's sample of 78 overtaking and passing accidents is not unusual.

Data on the injury accidents sampled in this study and the number of injuries resulting therefrom are shown in table 6. These are separated with respect to the type of accident. The table shows that the ratio of average injuries per accident (.51) is greater than that found in all accidents on all noncontrolled access rural highways (.20) (*9*). However, the severity of the injuries in the sampled accidents, as determined from the "Injured" section of the accident reports is minor, as shown in table 7. In over one-half of the overtaking accidents, injuries were limited to contusions, sprains, whiplash and/or minor lacerations and fractures. Similar minor injuries occurred in 45 percent of the passing accidents.

Data presented in table 8 summarizes the severity of accidents and average property damage per accident, based on estimates shown on the study's accident reports by type and location. Chi-square tests were made on the table's data to test the dependence between severity (non-injury and injury accidents) and accident location (driveways/intersections and nonintersections). The results showed that for both passing and overtaking accidents, the severity of the accidents is independent of accident location.

The average property damage estimates per accident were, as expected, higher for injury accidents than for non-injury accidents. There is little difference in the overall average property damage estimates for overtaking accidents by location. This is not true for passing accidents where the average property damage per nonintersection accident is more than double that of the same type accidents occurring at intersections and driveways. A probable explanation for this is that passing accidents occurring at intersections and driveways are usually same-direction sideswipes as vehicles enter from the right or exit to the left with estimated (from the accident reports) lower absolute velocities just prior to the accident. Few head-on collisions occur at these locations.

Reduction of Overtaking and Passing Accidents

Further consideration of the reduction of overtaking and passing accidents through the employment of a remedial-aid system must take into account those overtaking and passing maneuver accidents which might have been avoided through the use of such a system. All

Table 5.—Overtaking and passing accidents by location

Accident type	Total	Intersection		Driveway		Nonintersection/ driveway	
		Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Overtaking	42	11	26	10	24	21	50
Passing	36	4	11	6	17	26	72
Total	78	15	19	16	21	47	60

Table 6.—Number and percent of overtaking and passing accident injuries

Accident type	Accidents	Injury accidents		Injuries	Mean injuries/accident
	Number	*Number*	*Percent*	*Number*	*Percent*
Overtaking	42	11	26	17	0.40
Passing	36	13	36	20	.55
Other	104	[1] 30	29	[1] 55	.53
Total	182	54	30	92	[2] .51 [3] .47

[1] Includes three fatal accidents and three fatalities.
[2] All accidents.
[3] Overtaking and passing accidents only.

Table 7.—Severity of injuries sustained in all accidents

Severity rating[1]	Injuries[2] Overtaking		Passing		Other	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Minor (contusions, sprains, whiplash, minor lacerations and fractures of fingers, toes or nose)	11	64.7	9	45.0	41	74.5
Moderate (disfiguring lacerations, simple bone fractures, etc.)	5	29.4	8	40.0	6	10.9
Severe (compound fractures, dislocations of extremities, loss of eyes, crushing of fingers or toes—not dangerous, survival normally assured)	1	5.9	2	10.0	5	9.1
Serious (lacerations with dangerous hemorrhage, crushing of extremities, skull fracture etc.—dangerous, survival probable)	0	0.0	1	5.0	0	0.0
Critical (survival uncertain, includes fatal termination beyond 24 hours)	0	0.0	0	0.0	0	0.0
Fatal (fatal within 24 hours)	0	0.0	0	0.0	3	5.5
Total	17	100.0	20	100.0	55	100.0

[1] Rating scale is same as that used in the Cornell Aeronautical Laboratory ACIR studies (*10*).
[2] Includes all drivers and passengers shown on the study's accident report forms.

Table 8.—Property damage and number of overtaking and passing accidents by severity and location

Accident type	Accident total	Driveways/intersections Number of accidents	Property damage Total	Property damage Accident average	Nonintersections Number of accidents	Property damage Total	Property damage Accident average
Overtaking							
Noninjury	31	17	$7,825	$463	14	$7,330	$524
Injury	11	4	2,574	643	7	4,720	674
Subtotal	42	21	10,399	495	21	12,050	574
Injuries	15	7			8		
Passing							
Noninjury	23	8	2,365	296	15	7,513	501
Injury	13	2	1,390	695	11	13,053	1,187
Subtotal	36	10	3,755	376	26	20,566	791
Injuries	22	2			20		

Table 9.—Average property damage estimating per *passing* accident ($)—original vs. remedial-aid sample

Accident severity	Nonintersection/driveway accidents: Original sample Accidents	Original sample Average cost	Remedial-aid sample Accidents	Remedial-aid sample Average cost
Noninjury	15	$501	10	$569
Injury	11	1,187	8	1,273

Table 10—Property damage cost per vehicle mile for overtaking and passing accidents

Accident type	Number of accidents	Total property damage	Study sample vehicle miles (millions)	Property Damage per vehicle mile
Overtaking	42	$22,449	[1] 64.9	$0.00035
Passing	28	15,878	64.9	.00025

[1] As shown in table 1.

accidents in the sample which were classified as either overtaking or passing were reviewed with the aforementioned objective in mind. From tables 2 and 3 it was determined that only those accidents resulting from driver control errors and mechanical failures would not have been avoided through use of any remedial overtaking and passing system. In the passing category six accidents were attributed to driver control errors; e.g., ran off the roadway while attempting or completing a passing maneuver, and two accidents were attributed to mechanical failures. None of the eight accidents occurred near an intersection or a driveway. In the overtaking category no accidents were attributed to driver control errors or mechanical failures.

Reducing the passing accident sample by the eight accidents just mentioned leaves a total of 70 accidents, or 38.4 percent of the original 182 accident sample that might have been avoided by using a remedial overtaking and passing system. The 70 accidents consist of 42 overtaking accidents and 28 passing accidents.

Examination of the property damage estimates of the reduced passing accident sample shows that the average property damage estimate, per nonintersection passing accident, increases by severity. These increases are shown in table 9 which contains the data for the original between intersection passing accident sample of 26 accidents and remedial aid passing accident sample of 18 accidents. With no change in the intersection/driveway passing accident sample size, the average property damage of accidents occurring at such locations remained the same as that shown in table 8. Similarly, with no change in the overtaking accident sample size, both between and at intersections, the average property damage of overtaking accidents shown in table 8 has not changed.

Table 10 presents another way of looking at the costs of those overtaking and passing accidents which might possibly be eliminated through the implementation of a remedial-aid system. The property damage costs shown: $0.00035 and $0.00025 per vehicle-mile for overtaking and for passing accidents, respectively, are used in the following section to determine probable property damage savings through implementation of a remedial overtaking and passing system.

Table 11.—Comparison of study and Virginia two-lane rural primary system data—1966

Statistic	Virginia two-lane rural primary system (*11*)	Study section	
		Total accident sample	Reduced accident sample [1]
Highway miles	6,393	36	36
Vehicle miles .... millions	5,223	64.9	64.9
Total accidents .... per year	16,319	182	70
Accident rate .... per 100 MVM	312	280	108
Accident property damage .... per year ($10,000)	954	13	4
Percentage of two-lane rural primary system			
Miles	100%	0.56%	0.56%
Travel	100	1.24	1.24
Total accidents	100	1.12	0.43

[1] Those accidents that might be reduced through implementation of a remedial overtaking and passing driver-aid system.

Potential Remedial Aid Benefits

The accident report sample analyzed for this study provides only limited insight into the extent of overtaking and passing accidents on two-lane rural highways. Actually, these types of accidents constitute a sizable portion of accident statistics for such highways as shown below.

Table 11 compares the accident sample taken to similar data for that portion of the Virginia rural primary system which is two lane. The table shows that the sample represents less than 1 percent of the total accidents occurring in 1 year on the system and that for the sample, 38 percent (70 of 182 accidents) are amenable to overtaking and passing driver aids. If this percentage holds true for Virginia's entire two-lane rural primary system, there are over 6,000 overtaking and passing accidents occurring annually on the highway system that might be reduced through implementation of such driver aids.

The closeness of the accident rates for the sampled mileage—280 accidents per 100 MVM (million vehicle-miles), and the two-lane rural primary system—312 accidents per 100 MVM, provides some justification for using the two sets of data to make preliminary predictions of possible savings by using remedial overtaking and passing driver aids. Accordingly, dollar savings that might result from a reduction in overtaking and passing accidents through implementation of such aids were calculated using the property damage costs per vehicle-mile shown in table 10 and the traffic and mileage data discussed next.

Table 12.—Ten-year potential overtaking and passing remedial aid accident cost reduction

Remedial aid—degree of effectiveness	Cost reductions (millions of dollars)		
	Overtaking	Passing	Total
Low (10% accident reduction)	$76	55	$131
High (70% accident reduction)	535	382	917

Nationwide, there are 642,039 miles of Federal-aid and State primary rural surfaced highways (*12*). Of this mileage, 87 percent is two lane, 27 percent consists of roadways from 20 to 35 feet with an ADT in excess of 2,000 vehicles per day. This latter mileage of 151,067 miles, which carries 218.3 billion vehicle miles of travel annually, is where remedial overtaking and passing driver aids could be of significant value (*13*). For this amount of travel the expected reduction in overtaking and passing accident property damage costs over a 10-year period, assuming different levels of effective remedial aids, is as shown in table 12. The less effective systems, which could produce $131 million in safety benefits, would be more typical of low cost passive aids ($100/mile) such as markers along a roadway which would designate either the remaining length of a passing zone or available remaining sight distance. Effective, but more costly, dynamic aids ($5,000 to $35,000/mile) such as an electronic closed loop system, could produce during a 10 year expected lifetime nearly one billion dollars of safety benefits. There are, of course, numerous other direct and indirect savings which could also be accrued but which have not been treated here. For example, provision of additional passing opportunities through a remedial aid should reduce travel time, promote smoother flow, and cause a reduction in operating costs. Assisting a driver in the overtaking maneuver should reduce erratic braking maneuvers and hence operation costs. In addition, driver tension should be markedly reduced, especially during adverse visibility conditions.

Summary and Conclusions

In attempting to make cost effectiveness analyses of various passive and dynamic traffic control devices, often the accident data cannot be directly related to what the device is intended to alleviate. Such was the case for remedial rural two-lane overtaking and passing driver aids. This study, supplemented by the results of "Identification and Evaluation of Remedial Aid Systems for Passing Maneuvers on Two-Lane Rural Roads," (*14*) now provides the overtaking and passing accident information required for meaningful cost effectiveness analysis of potential remedial overtaking and passing traffic control devices.

Using the descriptive portions of 182 reports of accidents occurring in 1 year on 35 miles of two-lane rural highway in Virginia and carrying 2,500 to 6,800 ADT, it has been shown that 20 and 23 percent, respectively, of rural two-lane accidents involve passing and overtaking maneuvers. The accident rate per 100 MVM for the sampled mileage (280) is extremely close to that for the entire 7,630-mile Virginia two-lane rural primary system (312).

In-depth analysis of the accident reports also showed that data in those sections of the report pertaining to "Driver Actions Indicated" and "What Drivers Were Doing" are *not* reliable measures for classifying accidents by type of driving maneuver.

Overtaking Accidents

Further analysis of the *overtaking* accidents showed that:

- Forty-five percent involved a vehicle stopped in roadway.
- Fifty percent did *not* occur at an intersection or driveway.
- The estimated speed differential between involved vehicles, just prior to the collision, often exceeded 20 m.p.h.
- The number of injuries per accident (0.40) is double that found in all noncontrolled access rural highway accidents, but are very minor in severity.
- There is no significant difference in the average property damage cost per accident by location (driveways/intersections vs. nonintersections). Overtaking accident costs amount to $0.00035 per vehicle-mile.
- Overtaking remedial driver aids, depending on their degree of sophistication and if implemented on that portion of Federal-aid and State primary rural surfaced highways with ADT's in excess of 2,000, could produce *annual* accident cost savings ranging from 8 to 54 million dollars.

Passing Accidents

Similar detailed analysis of the passing accidents showed that:

- More (25 percent) occurred during the passing of a left-turning vehicle than for any other single situation.
- Eleven percent occurred at intersections, where passing is normally prohibited.
- The number of injuries per accident (0.55), like that for overtaking accidents is double that found in all noncontrolled access rural highway accidents. As expected, the injury severity of these accidents was greater than that for overtaking accidents but independent of accident location (driveways/intersections vs. nonintersections). However, the property damage cost per passing accident at intersections and driveways was only half of those occurring between intersections.
- Passing accident costs amount to $0.00025 per vehicle-mile.
- Under the same conditions for overtaking accidents, passing remedial driver aids could be expected to produce *annual* accident cost savings ranging from 6 to 38 million dollars.

REFERENCES

(*1*) "Accident Facts—1964 Edition," *National Safety Council,* 1964, p. 45.

(*2*) "Highway Statistics 1963," *U.S. Department of Commerce,* U.S. Government Printing Office, Washington, D.C., p. 107.

(*3*) National Safety Council, op. cit., p. 46.

(*4*) "Identification and Evaluation of Remedial Aid Systems for Passing Maneuvers on Two-Lane Rural Roads," *The Franklin Institute Research Laboratories, U.S. Department of Transportation* 1969, pp. 1-81, Vol. II.

(*5*) Solomon, D., Emery R., and Byington, S., "Design of A Passing Aid System," Prospectus No. 117, Appendix III, February 1967, pp. 1-9.

(*6*) "Summary of Accident Data, Calendar Year 1966," *State Highway Systems, Department of Highways, Commonwealth of Virginia,* 1967, p. 63.

(*7*) *Virginia Accident Report,* Form No. 105030.

(*8*) "Accident Facts-1968 Edition," *National Safety Council* 1968, p. 46.

(9) Ibid., p. 45.

(*10*) Ryan, Anthony, and Garrett, John W., "A Quantitative Scale of Impact Injury," *Cornell Aeronautical Laboratory,* 1968, pp. 1-25.

(*11*) "Summary of Accident Data," op. cit., pp. 46, 61-99.

(*12*) "Highway Statistics 1967," *U.S. Department of Commerce, U.S. Government Printing Office,* 1968, pp. 157, 172.

(*13*) Ibid, pp. 162, 180.

(*14*) *The Franklin Institute Research Laboratories,* op. cit.

Speed Analysis of Accidents on Interstate Highways

SPONSORED BY THE OFFICE OF RESEARCH

Reported by RICHARD L. BEATTY,
Vice President
Westat Research, Inc.

An analysis of accidents, speed, and related traffic parameters on rural and urban portions of the Interstate Highway System is presented in this article.

Phase I.—*The relationship between the speed of a vehicle before an accident and the severity of the accident is generally thought to be direct, i.e., the higher the speed the more severe the accident. This conclusion was at least partially substantiated in this study of single-vehicle accidents on between-interchange units of the Interstate System.*

The direct relationship between speed before the accident and number of injuries per accident was obvious for all times of day, manners of collision and area types. A statistically significant linear relationship between injuries per single-vehicle accident and speed before the accident existed in all cases.

The lack of observations somewhat inhibited the analysis of fatalities per single-vehicle accident as it related to speed before the accident. However, the data strongly imply that up to a speed of 55 m.p.h., fatalities per accident and speed before the accident are independent. At speeds before the accident in excess of 55 m.p.h., fatalities per accident increase very sharply with reported speed before the accident.

Phase II.—*Phase II of this research investigated a possible association between the dispersion in speeds of all traffic on an element of mainline Interstate highway and the difference between the speeds before the accident for vehicles involved in two-vehicle accidents. The study substantiated earlier results on conventional rural highways without control of access which indicated a significantly greater difference in speeds between the two accident-involved vehicles than two randomly selected vehicles.*

Introduction

THE objective of this analysis was to determine the relationship between reported speeds prior to a collision and accident severity. The analysis was restricted to single and two-vehicle accidents on the Interstate System between interchanges. The first phase looked at speed prior to collision versus accident severity for single-vehicle accidents. The second phase was restricted to two-vehicle accidents which occurred during the hours 9:00 a.m. to 4:00 p.m. and investigated the difference between the speeds of the accident-involved vehicles and the speed variation of traffic.

The measures of accident severity utilized were, for each accident (or vehicle), the number of injuries, the number of fatalities, and the amount of property damage. No attempt was made to combine these measures to form a single measure or index of severity.

The data used in this study were gathered by the Federal Highway Administration (FHWA) as part of the Interstate System Accident Research–Study II (ISAR). This research was a cooperative effort between the Federal Highway Administration and 24 State highway departments.

Each year States submitted traffic, highway or geometric, and accident data on selected sections of Interstate highway. The study sections are related to specific interchanges throughout the State and are further subdivided into specific study units. A unit is defined by the function it performs or its geometric characteristics. Thus, units are either types of ramps, types of speed change lanes, mainline units, or crossroad units. All units included in this report are mainline units between interchanges where there are no structures or unusual features such as a weigh station or toll booth.

The mainline units described above

Table 1.—Number and percent of single-vehicle accidents by type of area, type of highway, time of day, and type of accident

Time of day	Rural				Urban									
	Four-lane				Four-lane				Six-lane				Total	
	Collision		Noncollision		Collision		Noncollision		Collision		Noncollision			
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Day [1]	259	8.3	406	13.1	53	1.7	60	1.9	53	1.7	32	1.0	863	27.8
Rush hours [2]	148	4.8	239	7.7	44	1.4	42	1.4	50	1.6	28	.9	551	17.7
Night [3]	596	19.2	635	20.4	134	4.3	121	3.9	120	3.9	87	2.8	1,693	54.5
Total	1,003	32.3	1,280	41.2	231	7.4	223	7.2	223	7.2	147	4.7	3,107	100

[1] 9 a.m. to 4 p.m.
[2] 7 a.m. to 9 a.m. and 4 p.m. to 6 p.m.
[3] 6 p.m. to 7 a.m.

are the most frequently occurring and safest units in the data base. Hence, only a fraction (10-20 percent) of these units were actually utilized in the study, since the accident was the base of investigation rather than the study unit itself.

A thorough description of the data base is given in *Cirillo,* et. al. (*1*).[1] Although there have been considerable additions to the data base since this publication, the basic form of a unit of data has remained unchanged.

Analysis of Single-Vehicle Accidents

Data description

Geographical distribution.—Data from 21 States participating in ISAR—Study II were available during this phase of the analysis. A number of observations were no doubt lost through the editing procedure which required complete, valid *n*-tuples for every data point. Irrespective of the editing procedure, however, the amount of data submitted varies considerably from State to State due to differences in the States' financial and personnel resources. Of the 3,107 accident observations studied in this phase of the study, over half were from Indiana, North Carolina, and Virginia.

Other major classifications.—The number and percent of the single-vehicle accidents studied in this phase of the report are presented in table 1, according to selected major categories of interest: type of area, type of highway in urban areas, time of day when the accident occurred, and whether or not an accident involved a collision.

It is interesting to note that 73.5 percent of the recorded single-vehicle accidents occurred in rural areas. Fifty-four percent of the total number of accidents occurred at night. Slightly more than half of the accidents (53.1 percent) were noncollision accidents, i.e., the vehicle involved did not collide with any object.

The variables.—The first phase of the analysis considered all single-vehicle accidents recorded in the data base as multi-valued observations consisting of 29 values or values for 29 variables. An observation was used in the analysis only if there was valid data for every one of the 29 variables. A total of 3,107 such accidents were found to be usable.

A list of the variables, with a brief description of each, is presented in table 2. Many of the variables were taken di-

Table 2.—Variables in data base used in Phase I of speed analysis

Number	
X(1)	Unit length (feet)
X(2)	Area type (1—urban, 0—rural)
X(3)	Number of lanes
X(4)	Maximum curvature (degrees)
X(5)	Existence of structure (1—yes, 0—no)
X(6)	ADT [1]—morning rush (7–9 a.m.)
X(7)	ADT —evening rush (4–6 p.m.)
X(8)	ADT —daytime (9 a.m.–4 p.m.)
X(9)	ADT —(24 hour)
X(10)	Percent in-State cars—daytime
X(11)	Percent out-State cars—daytime
X(12)	Percent of vehicles, daytime, traveling at <40 m.p.h.
X(13)	Percent of vehicles, daytime, traveling at 40–49 m.p.h.
X(14)	Percent of vehicles, daytime, traveling at 50–59 m.p.h.
X(15)	Percent of vehicles, daytime, traveling at 60–69 m.p.h.
X(16)	Percent of vehicles, daytime, traveling at 70–79 m.p.h.
X(17)	Percent of vehicles, daytime, traveling at >80 m.p.h.
X(18)	Number of accidents on study unit in year
X(19)	Average daytime speed of all vehicles (m.p.h.)
X(20)	Standard deviation of daytime speed of all vehicles (m.p.h.)
X(21)	Previously/Not previously analyzed data (1—no, 0—yes)
X(22)	Hour of day of accident
X(23)	Manner of collision
X(24)	Vehicle type involved in accident
X(25)	Number of fatalities (this accident)
X(26)	Number of injuries (this accident)
X(27)	Amount of property damage (this accident)
X(28)	Speed before accident (m.p.h.)
X(29)	Difference between speed before accident and average daytime speed of all vehicles (m.p.h.)

[1] Average daily traffic (in thousands of vehicles).

[1] Italic numbers in parentheses identify the references on page 102.

rectly from the record on the study unit as submitted by the State, while some of the variables required decoding.

Variable X(2), area type, is an example of a variable created by decoding the recorded variable. The States record area type into six categories depending on whether the area surrounding the study unit is either: rural; urban with population less than 5,000; urban with population from 5,000 to 50,000; urban with population greater than 50,000; suburban with population from 5,000 to 50,000; or suburban with population greater than 50,000. These six categories were collapsed into two for this analysis. Rural, [X(2) = O] combines rural and urban with population less than 5,000. Urban, [X(2) = 1] is composed of the remaining four categories. Thus, the decoding process simply involved combining the recorded values in a specified way to form a new value.

Those variables which were essentially taken directly from the study unit record are X(1) through X(18) and X(22) through X(28). Variables X(1) through X(5) measure physical characteristics of the unit itself (or its surroundings) while X(6) through X(17) are concerned with the characteristics of the traffic on the unit for the year under study.

Both the count of vehicles traveling on the studied units of highway [X(6)–X(9)] and their speeds [X(12)–X(17)] were estimated from sample counts and observations taken by the States throughout the year. The variable X(18) is the total number of recorded accidents which occurred on the unit during the reported year.

Both X(19) (average daytime speed) and X(20) (standard deviation of the speed) were computed from the frequency distribution given by X(12) through X(17). These computations were straightforward applications to class interval frequency data except for the open intervals on each end. For "under 40 m.p.h." the representative value was taken to be 37.5 m.p.h. in rural areas and 32.5 m.p.h. in urban areas. For "80 m.p.h. or more" a figure of 85 m.p.h. was used for both areas. All three of these figures were based on speed trend research conducted by the FHWA. Variable X(21) simply indicates whether or not the unit record entered the data base since the last analysis.

Variables X(22) through X(28) represent characteristics of the particular single-vehicle accident generating the data point or observation. The hour of day of the accident, X(22), is a number from zero to 2400 indicating the time of the accident with midnight being equal to zero. Variable X(23) would ordinarily take on several different values for each manner of collision, such as, "head on", "rear end", and so forth. But, since only single-vehicle accidents are included here, only two categories—collision and noncollision—are coded. Collision indicates that the vehicle collided with a fixed object such as a guardrail, bridge pier, or sign. Noncollision means that the vehicle left the road without actually colliding with anything. The original coding of variable X(24), vehicle type, allowed for several categories. However, only two categories were used in this analysis. One category included all passenger cars and two-axle, four-tire trucks, while the other category contained all other trucks and all buses.

Table 3.—Average values for selected variables collected in Phase I, by area type

Description		Average value	
		Rural	Urban
Length of unit	feet	2,669	1,581
Maximum curvature	degree	0.55	1.09
Existence of structure (1=yes, 0=no)		0.475	0.640
Average daily traffic on unit (in vehicles)		4,809	17,789
In-State passenger cars—daytime	percent	48.5	66.2
Out-State passenger cars—daytime	do	33.7	18.5
Average daytime speed—all vehicles	m.p.h.	60.7	58.7
Speed before accident	do	55.8	54.1

Geometrics and traffic variables.—Table 3 further describes the study units utilized in the analysis of single-vehicle accidents. This table, gives the average values for a selection of variables describing the study units which make up the accidents considered in this section of the report. The geometric variables given in table 3 are limited to unit length, maximum curvature and whether or not a structure was present. As expected, the longer straighter units appear in rural areas. The smaller proportion of units with a structure in rural areas might help to explain the higher proportion of noncollision type accidents recorded in rural areas.

The most notable difference between urban and rural study sections involves traffic volume. The average ADT was about 4,800 vehicles for study units in rural areas and nearly 17,800 for study sections in urban areas. Even on a per-lane basis, since some six-lane highways are included in the urban averages, the volume of traffic on urban highways is still about three times greater. It should also be noted that although the total percent of passenger vehicles is estimated to be about the same in urban and rural areas, the rural study units have about twice as many out-of-State vehicles as urban areas.

The speed variables presented in table 3 indicate that the average speed of 60.7 m.p.h. on the rural highway sections exceeds that on urban sections by 2 m.p.h. The reported speed of the vehicle before the accident is also, on the average, about 2 m.p.h. less on urban highways than on rural highways.

Accident severity.—The severity of the single-vehicle accidents studied in this phase of the research is reflected in the injuries, fatalities, and property damage connected with the accidents. Reported with the 3,107 accidents studied were 1,661 injuries, 83 fatalities, and over 2.75 million dollars of property damage. On a per-100 accident basis there were, on the average, 53.46 injuries, 5.00 fatalities, and $88,640 in property damage. Stated another way, the data indicate that injuries occur with a frequency exceeding one in every two single-vehicle accidents while a fatality occurs about once in every 20 single-vehicle accidents and the average reported property damage for single-vehicle accidents is $886.40.

Table 4 presents detailed breakdowns for these severity criteria for the accident data from table 1. Table 4 gives both number and percent of accidents,

Table 4.—Number and percent of accidents, injuries, fatalities, and amount of property damage associated with single-vehicle accidents by type of area, type of highway, time of day, and collision or noncollision

Time of day[1]	Rural				Urban								Total	
	Four-lane				Four-lane				Six-lane					
	Collision		Noncollision		Collision		Noncollision		Collision		Noncollision			
	Number or Amount	Percent	Number or Amount	Percent	Number or Amount	Percent	Number or Amount	Percent	Number or Amount	Percent	Number or Amount	Percent	Number or Amount	Percent
Day														
Accidents	259	8.3	406	13.1	53	1.7	60	1.9	53	1.7	32	1.0	863	27.8
Injuries	126	7.6	255	15.4	13	0.8	39	2.3	22	1.3	17	1.0	472	28.4
Fatalities	8	9.6	6	7.2	2	2.4	0	0.0	0	0.0	0	0.0	16	19.3
Property damage[2]	218	7.9	392	14.2	38	1.4	33	1.2	22	0.8	9	0.3	712	25.8
Rush-hour														
Accidents	148	4.8	239	7.7	44	1.4	42	1.4	50	1.6	28	0.9	551	17.7
Injuries	90	5.4	184	11.1	16	1.0	25	1.5	18	1.1	22	1.3	355	21.4
Fatalities	4	4.8	4	4.8	1	1.2	0	0.0	0	0.0	0	0.0	9	10.8
Property damage[2]	127	4.6	218	4.9	24	0.9	28	1.0	21	0.8	9	0.3	427	15.5
Night														
Accidents	596	19.2	635	20.4	134	4.3	121	3.9	120	3.9	87	2.8	1,693	54.5
Injuries	242	14.6	326	19.6	64	3.9	76	4.6	85	5.1	41	2.5	834	50.2
Fatalities	28	33.7	18	21.7	1	1.2	3	3.6	5	5.0	3	3.6	58	69.9
Property damage[2]	535	19.4	766	27.8	107	3.9	110	4.0	66	2.4	31	1.1	1,615	58.6
Total														
Accidents	1,003	32.3	1,280	41.2	231	7.4	223	7.2	223	7.2	147	4.7	3,107	100.0
Injuries	458	27.6	765	46.1	93	5.6	140	8.4	125	7.5	80	4.8	1,661	100.0
Fatalities	40	48.2	28	33.7	4	4.8	3	3.6	5	5.0	3	3.6	83	100.0
Property damage[2]	880	32.0	1,376	50.0	169	6.1	170	6.2	109	4.0	48	1.8	2,754	100.0

[1] Day=9 a.m. to 4 p.m.; Rush-Hour=7 a.m. to 9 a.m. and 4 p.m. to 6 p.m.; Night=6 p.m. to 7 a.m.

[2] Thousands of dollars.

fatalities, injuries and amount and percent of property damage by area type, collision type, highway type and time of day. The table is set up to facilitate the comparisons, within each cross-classification, of the relative frequencies of each severity measure. Thus, in each cell, or cross-category, the percentages of injuries, fatalities, and property damage can be compared with that of accidents. Percentages smaller than that for accidents imply a rate of occurrence less than average, with larger percentages implying higher relative frequencies.

The absolute number of injuries, fatalities and amount of property damage are, of course, highly related to number of accidents, and thus the data of table 4 generally follow the same pattern as in table 2.

The nighttime and rural area occurrences tend to dominate the data base, especially with respect to fatalities and property damage. Of all fatalities and property damage reported in the single-vehicle accidents included in this study, over 82 percent were reported from rural areas. Only three fatalities occurred in the 362 accidents reported in urban areas during either the day or rush-hour times. Also, almost 70 percent of all fatalities and slightly under 60 percent of all property damage was reported from nighttime accidents.

Further comparisons of the severity measures can be seen from table 5. This table presents injuries, fatalities, and property damage on a per-100 accidents basis for major cross-classifications of types of area, highway, collision, and time of day. In this table, it is meaningful only to compare injury rates with other injury rates, fatality rates with other fatality rates, and the property damage rates only with other property damage rates. Therefore, table 5 has three distinct sections, one each for injuries, fatalities, and property damage. Comparison of the rows in each section contrasts severity measure by time-of-day. Column comparisons include type of area, type of highway, and collision versus noncollision.

A word of caution is in order concerning each of the rates given in table 5.

Tables 5.—Average number of injuries and fatalities per 100 single-vehicle accidents and average dollar amount of property damage per single-vehicle accident, by type of area, type of highway, time of day and collision or non-collision

Severity measure and time of day[1]	Rural		Urban				Total
	Four-lane		Four-lane		Six-lane		
	Collision	Noncollision	Collision	Noncollision	Collision	Noncollision	
Injuries							
Day	48.65	62.81	25.53	65.00	41.51	53.12	54.69
Rush-hour	60.81	76.99	36.36	59.52	36.00	78.57	64.43
Night	40.60	51.34	47.76	62.81	70.83	47.13	49.26
24-hour	45.66	59.77	40.26	62.78	56.05	54.42	53.46
Fatalities							
Day	3.09	1.48	3.77	0	0	0	1.85
Rush-hour	2.70	1.67	2.27	0	0	0	2.54
Night	4.70	2.83	.75	2.48	4.17	3.45	3.43
24-hour	3.99	2.19	1.73	1.35	2.24	2.04	2.67
Property damage (in dollars)							
Day	842	966	718	543	406	272	836
Rush-hour	858	911	548	678	416	328	775
Night	898	1,206	799	910	553	351	954
24-hour	877	1,075	733	763	490	330	886

[1] Day : 9:00 a.m. to 4:00 p.m.
Rush-Hour: 7:00 a.m. to 9:00 a.m., and 4:00 p.m. to 6:00 p.m.
Night : 6:00 p.m. to 7:00 a.m.

If each of these rates is thought of as a sample estimate of a population[2] parameter, then they are subject to sampling error or variations from the true measure due to the fact that not every item in the population was considered. The usual measure of the sampling variation is a quantity referred to as the standard error of the estimate. This absolute measure of the error in the estimate is made relative by dividing it by the estimate itself. The ratio of the standard error of the estimate to the estimate is called the coefficient of variation. This measure is relative, independent of the units or magnitude of the original data and frequently expressed as a percent.

A coefficient of variation of 10 percent is frequently used as a minimum standard. This would mean, using a normal distribution assumption, that the sample estimate would differ from the value being estimated by something less than 20 percent of the estimate, about 95 percent of the time. This latter figure would be 75 percent using only a finite mean and variance assumption. This statement is based on the Tchebysheff's inequality or the law of large numbers (*2*). A reduction in the coefficient of variation would lead to reductions in the relative errors for the same probability levels. The coefficient of variation is directly proportional to the standard error which is inversely proportional to the square root of the sample size. Thus, the relative error associated with any estimate can be reduced by increasing the number of observations on which the estimate is based. In the present case, the standard errors are such that sample sizes of just under 300 are needed to approximate a coefficient of variation of 10 percent for either injury or property damage rates. Since fatalities, even though conditioned on the occurrence of an accident, are a relatively rare happening, the necessary number of accidents is nearly 3,600 for a coefficient of variation for fatality rates of 10 percent.

Lack of sufficient observations to produce an estimated coefficient of variation of 10 percent does not, by itself, invalidate the estimated rates. It simply means that the coefficient is greater than 10 percent. In order to guide the reader in interpreting table 5 as well as later material, table 6 is presented. This table presents *approximate* coefficients of variation for different numbers of observed accident occurrences for each of the three severity rates discussed here. Table 6 in conjunction with the accident frequencies given in both tables 1 and 4 are

[2] It is easy to visualize the population of all single-vehicle accidents on Interstate highways with each cross-classification a subpopulation. Obviously the data are a sample from this population and the resulting subpopulations. Whether these samples are random, which is very necessary to this discussion, is open to serious question.

Table 6. — Approximate[1] sample sizes (number of accidents) needed to obtain 10, 20, and 30 percent coefficients of variation for injury, fatality and property damage rates per accident

	Coefficient of variation		
Rate	*10%*	*20%*	*30%*
Injury	290	70	30
Fatality	3,750	940	420
Property damage	220	60	25

[1] Approximations are based on estimated means and variances of the observed numbers of amounts for rural areas only. If all 3,107 observations had been used, the numbers above would have been slightly lower for injuries but somewhat higher for both fatalities and property damage.

therefore available to judge the reliability of the rates given in table 5. The reader should, when using a coefficient of variation of *P* percent, keep in mind that an error in the estimate of up to 2*P* percent would not be considered extreme.

Now, referring back to table 5, there are a number of noteworthy comparisons. One of the most consistent differences of trends in rates concerns that of property damage. The property damage reported per nighttime accident is consistently higher than for either daytime or rush-hour accidents, for all types of areas, highways, and collisions. Also, on 4-lane highways, especially in rural areas where most of the data are, the property damage per accident is significantly higher for noncollision types of accidents than for collisions.

Fatality rates were virtually nonexistent during the daytime or rush hour in urban areas except for collisions on 4-lane highways. However, the number of accident observations was generally too small for reliable estimates in any urban breakdown. In rural areas, the big differences seem to be higher occurrences per accident for nighttime and for collisions as opposed to noncollisions.

The various cross-classifications seem to show few consistent differences or trends with respect to injuries per accident. However, in total, injury rates seem to be highest during the rush hours and lowest at night and generally higher, especially in rural areas, for the accidents not involving a collision.

Speed–severity relationships

Speed before accident.—For each single-vehicle accident used in this study, the speed of the vehicle at the time immediately preceding the accident was recorded. The reliability of this speed figure varies a good deal both within and between geographical areas. Many times, the speed is that reported by the driver of the vehicle. Other times, this speed may be estimated by an investigating officer or determined as the result of an investigation of the accident.

Overall, there is probably some downward bias in what is reported as vehicular speed before the accident. The amount of the bias and its relationship with true speed is not known and its determination was not considered in this analysis. It is the purpose here to investigate the relationships between reported speeds and severity measures. If there is a meaningful relationship between these variables, it is doubtful that it would not exist after removal of speed biases.

It is reasonable to assume that if severity is related to speed before the accident, the relationship will be direct. That is, higher speeds will accompany more severe accidents. Similarly, the amount of downward bias would seem to be directly related to speed. The higher the speed, the more downward bias. Hence, if a direct relationship between speed before the accident and severity of the accident is found in the present set of data, this relationship would probably be accentuated rather than dampened by removal of speed bias.

As a final word on bias, the reader is referred to table 3. Here the estimated average speeds of all vehicles on the units studied is presented as is the average of the speeds of accident-involved vehicles before the accident. These average speeds are given separately for observations in urban and rural areas. As can be seen, the speed of the vehicles before the accident is on the average 4.6 m.p.h. less in urban areas and 4.9 m.p.h. less in rural areas than is the average speed of all vehicles traveling on the same units of highway. These values give some indication of the lower limit on the average magnitude of downward bias in the speed-before-the-accident figures. If it is assumed that involvement in a single-vehicle accident is independent of the speed of the vehicle then it would be expected that average speed of all vehicles would equal average speed of vehicles before accident involvement. Further, if speed and involvement are related it would logically seem to be in the opposite direction of that reported.

Measures of severity.—These are two values recorded for each accident which in some way indicate the severity of the accident. These values are the number of fatalities and the number of injuries. Each of these values has merit as a measure of accident severity and each will be investigated here as it is related to speed of the vehicle prior to the accident. No attempt was made to combine the three values into a single measure of the severity of the accident.

Occurrences per accident will be used to indicate severity rather than total number or amounts. This eliminates differences due only to number of occurrences and allows severity comparisons across sub-classifications of the data.

Number of observations.—In the preceding discussions, the data have been recorded for various cross-classifications such as area type, highway type, and time of day. Traffic characteristics were known to vary considerably among the categories and, as has been shown, severity rates for observed single-vehicle accidents also show many differences. Thus, it makes sense to subclassify the data as much as possible to remove causes of variation not under study. However, as the number of cross-classifications increases, the number of observations per cell decreases. As discussed earlier, the reliability of the computed severity measures decreases with the sample size and this is especially critical with regard to fatality rates.

Investigation of the speed–severity relationship requires, of course, a further classification of the data by levels of the variable reflecting speed before the accident. Thus, it is not feasible to investigate relationships between speed and severity within all the subcategories used earlier because of the very small numbers of observations per cell which result. Also, even though speeds were recorded to the nearest 5 m.p.h., the very low and very high speed intervals have been collapsed because of the scarcity of observations in these extreme categories.

Table 7 presents the number of single-vehicle accidents falling in selected intervals of recorded speeds before the accident, broken down by area type as well as total. This table indicates somewhat the numbers of observations available at each speed level. Clearly, further subclassification by either time-of-day or type of collision would further reduce these numbers.

The discussion which follows will investigate the severity of single-vehicle accidents as related to the reported speed of the vehicle before the accident only with regard to each of three major classifications of the data. These are as follows:

(1) Area type: urban and rural.

Table 7.—Number of single-vehicle accidents by recorded speeds before the accident and by area type

Recorded speed before accident (in m.p.h.)	Number of accidents		
	Urban	Rural	Total
Less than 42.5	232	111	343
42.5–47.4	192	81	273
47.5–52.4	386	126	512
52.5–57.4	348	162	510
57.5–62.4	529	175	704
62.5–67.4	361	118	479
67.5 and greater	235	51	286
Total	2,283	824	3,107

(2) Time of day: day (9:00 a.m. to 4:00 p.m.), night (6:00 p.m. to 7:00 a.m.), and rush hour (4:00 p.m. to 6:00 p.m. and 7:00 a.m. to 9:00 a.m.).

(3) Type of collision: collision and noncollision.

Injuries and speed.—The average number of injuries per single-vehicle accident in urban and in rural areas as related to speed before the accident is given in figures 1a and 1b. These figures illustrate a rather clear direct relationship between the average number of injuries per accident and the reported speed of the vehicle immediately preceding the accident. That is, injuries per accident do, on the average, increase as the speed before the accident becomes greater.

To further illustrate the relationship between injuries and speed, straight lines have been fit to the data plotted in figures 1a and 1b. These lines are shown and marked on the graph. The formulas for the fitted lines are also given. The appropriateness of the linear fit is visually clear for both area types although a second degree equation might have fit better in rural areas.

The straight lines plotted in figures 1a and 1b are the regression of injuries per accident on speed before the accident and were fit using a least squares technique applied to the individual data points rather than the group averages which form the basis of the line diagram. Under random sampling assumptions, the reduction in the injury rate sum of squares due to the regression on speed is highly significant (probability less than .01) in the statistical sense for accidents in both urban and rural areas. Hence, the chances of linear relationships as strong as those portrayed in figures 1a and 1b being due to chance alone would be extremely slight. Thus, based on the single-vehicle accidents being investigated here, there is little doubt that a direct relationship exists between injuries per accident and speed of the vehicle before the accident.

Referring to the equations given in figures 1a and 1b, it is of interest to note the magnitude of the coefficients of X in the two equations. These values are the slopes of the two lines and represent estimates of the increase in injury rates associated with unit increases in the speed of the vehicle before the accident. In particular, in rural areas, it is estimated that a speed of 10 m.p.h. faster before an accident increases the average number of injuries per accident by .132. This estimated increase is .089 in urban areas.

It should be pointed out further that the square of the correlation coefficient is only .026 for rural data and .016 for data from urban areas. The square of the correlation coefficient can be thought of as indicating what proportion of the variation in injuries per accident is due to the speed before the accident. The conclusion is simply that although the linear relationship is very strong, the predictive power is not impressive for an individual accident.

Figures 2 and 3 present graphically the relationship between injuries per accident and speed before the accident for types of collision and for times of day, respectively. Although straight lines have not been plotted on the graphs, the linear relationships are clear. In every case, least squares regression lines were fit and were statistically significant (probability .05 or less).

Fatalities and speed.—The analysis of the relationship between fatalities and speed before the accident is somewhat more affected by the observed number of

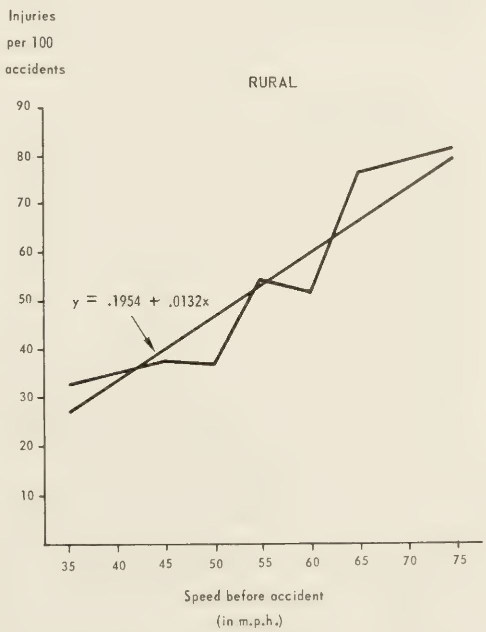


Figure 1a.—Average reported number of injuries per 100 accidents observed by speed before the accident for rural areas, including fitted regression line.

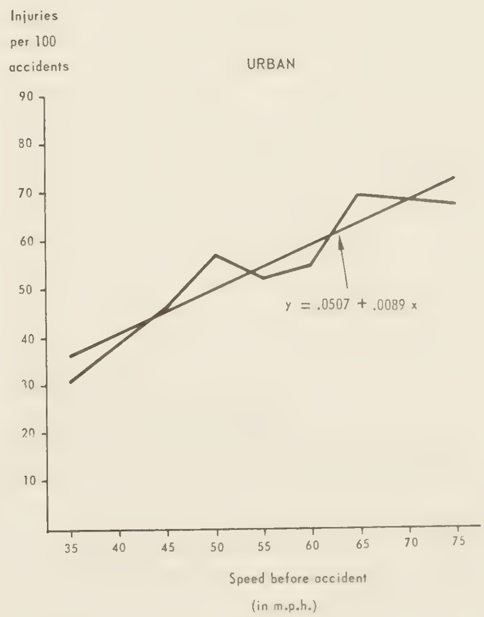


Figure 1b.—Average reported number of injuries per 100 accidents observed by speed before the accident for rural areas, including regression line.

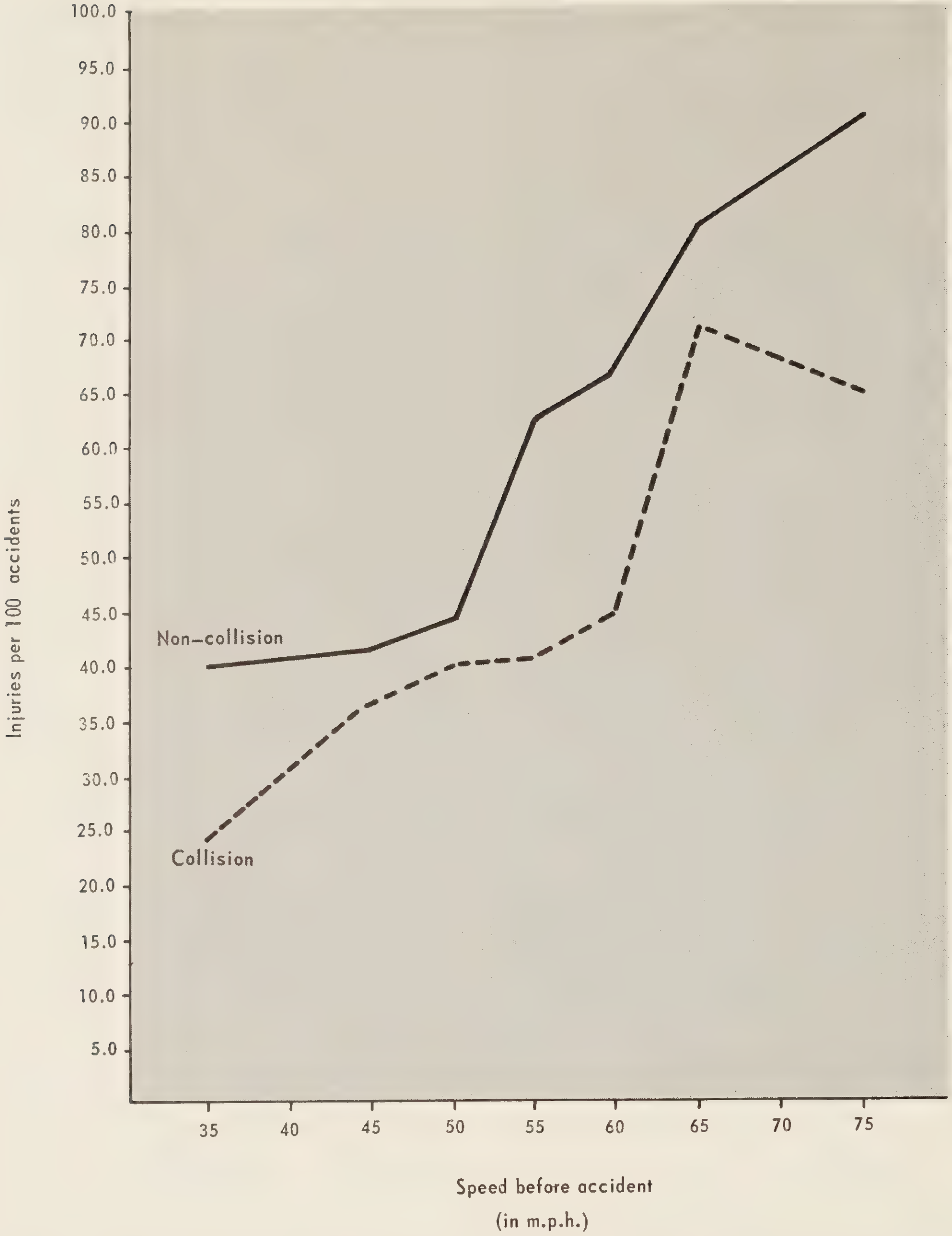


Figure 2.—Average reported injuries per 100 single-vehicle accidents observed, by speed before the accident and by type of collision.

accidents than for either injuries or property damage. Reference is made to table 6 where estimated numbers of observations required to achieve certain magnitudes of the coefficient of variation are presented. More than 10 times the number of accidents is required for fatality rate estimation than for either injury or property damage rates to attain the same level of relative precision. An estimated 420 observed accidents are needed to assure estimated fatality rates with a coefficient of variation of .30. Thus, to be relatively confident of estimated fatality rates within 50 percent of the true rate requires about 500 accident observations. It is clear, therefore, that to attain reasonable reliability in the studied fatality rates, only a limited amount of cross-classifications in addition to the speed groupings is possible.

Figure 4 presents fatalities per 100 accidents for the same speed-before-the-accident groupings as used earlier. Urban and rural areas are plotted separately so that only one of the plotted points is based on more than 400 accident observations (60 m.p.h. in rural areas). Some of the urban data points are based on less than 100 observed accidents so that estimation errors in excess of 100 percent would not be unlikely. However, in spite of the possibilities of sampling errors, there is little reason to question the overall relationships illustrated in figure 4. The graphs for the other subclassifications result in the same general pattern and are not presented here.

To further substantiate the magnitude and pattern of fatalities per 100 accidents at various reported speeds before the accidents, figure 5 is presented. The data plotted on this graph are totals and have not been subclassified. Further, the lowest and highest speed groupings have been combined so that every point plotted on this figure is based on at least 500 accident observations. Thus, the estimated coefficients of variation associated with the points are something less than 30 in each case.

In figure 5, the point plotted at a speed of 40 m.p.h. represents the average fatalities per 100 accidents for all accidents with reported speeds before the accident of less than 47.5 m.p.h. At the other end of this scale, the point plotted at 70 m.p.h. is the average for all accidents with reported speeds in excess of 62.5 m.p.h. before the accident.

Both figures 4 and 5 show the highest fatalities per 100 accidents at the highest speed before the accident. Also, in both cases, fatality rates for accidents with reported speeds of 55 m.p.h. immediately preceding the accident are lower than for accidents reported in most other speed groupings either above or below 55 m.p.h. With respect to this latter property, there seems to be no reasonable explanation for the lower fatality rates at speeds of 55 m.p.h. Investigation of the data using cars only does not result in a noticeably different pattern of points.

With regard to the higher fatality rates at the highest speed before the accident, this would seem to be a logical circumstance. However, the overall relationship between fatalities per 100 accidents and speed is not clear. It might be that there is no relationship for speeds less than some speed value greater than 55 m.p.h. But, beginning with this unknown speed value, the relationship is linear for the remainder of the speed scale. However,

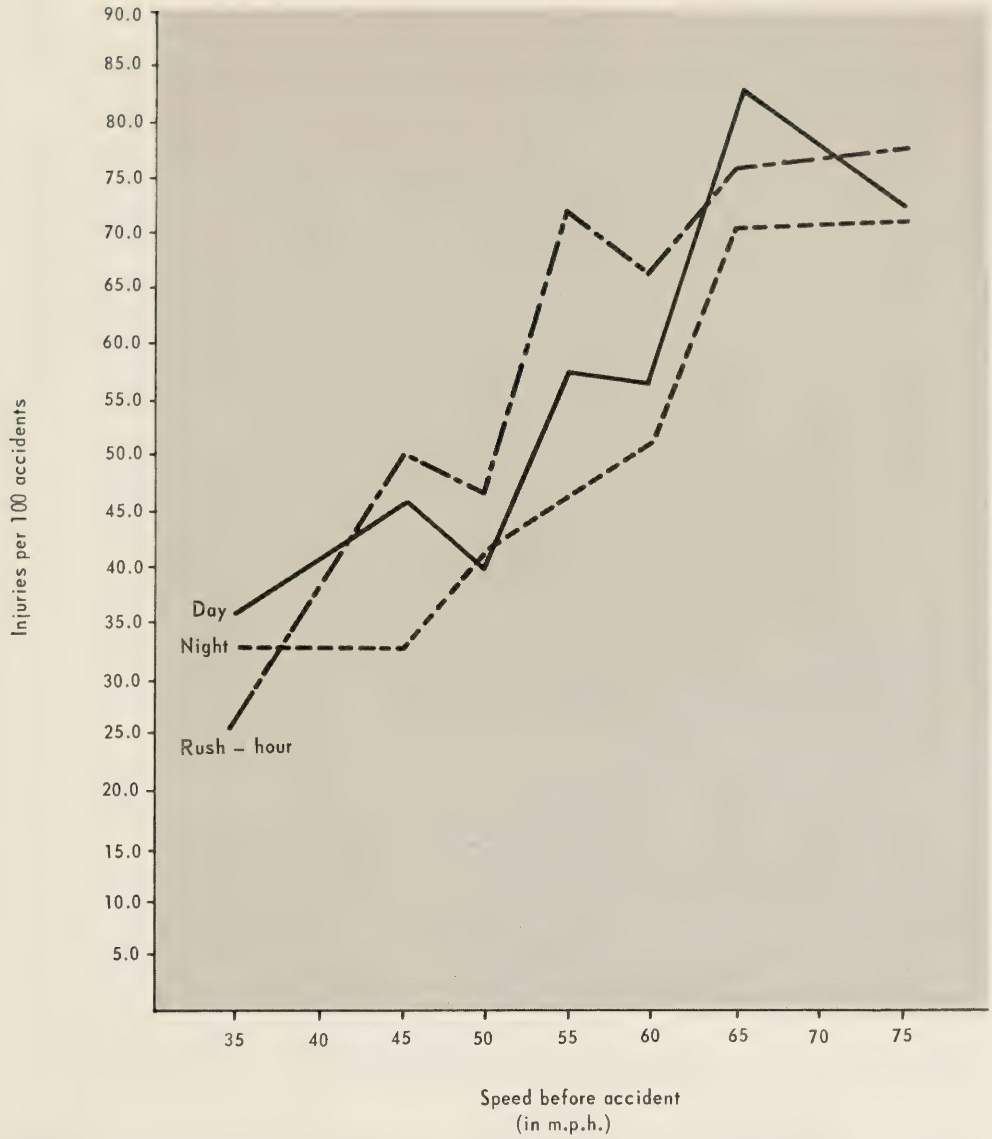


Figure 3.—Average reported injuries per 100 single-vehicle accidents observed, by speed before the accident and by time of day.

the data only mildly support a hypothesis such as this.

A more likely theory would hypothesize a nonlinear relationship with increases in fatalities per 100 accidents at a constant or even increasing rate as speed before the accident increases from some arbitrary speed exceeding 55 m.p.h. A possible functional relationship might be of the form

$$Y = e^{-L(1/x)}$$

where Y is fatality rate, X is speed before the accident, and L is some linear function of the reciprocal of X with unknown parameters. Some evidence of this more complicated type of relationship is evident in figure 6, which gives more detail at the high speeds although the sample sizes are relatively small. This figure utilizes rural data only (where most of the fatalities occur) and plots individual 5 m.p.h. intervals beginning with a midpoint of 45 m.p.h. through 75 m.p.h. All accidents with reported speeds before the accident exceeding 77.5 m.p.h. are combined to compute the last point which is plotted at the average speed value of approximately 85 m.p.h. The line diagram of figure 6 implies a very rapid relative increase in fatalities per 100 accidents for the high speeds before the accident. This type of relationship could be approximated by the equation of the form indicated.

Analysis of Two-Vehicle Accidents

Data description

The data base.—The data base for this phase of the study was drawn from the master file discussed in the introduction to this report. Only two-vehicle, daytime accidents on mainline Interstate highway units between interchanges were investigated in the second part of this analysis. A total of 721 of these accident observations were extracted from the master data file.

The geographical distribution of the data points used in this phase of the study is essentially the same as that for Phase I.

The number and percentage breakdown for various categories of the 721 two-vehicle accident observations is presented in table 8. The separation between urban and rural areas is maintained here as it was throughout Phase I. Other major classifications of the data concern the manner of collision and the movement of the two vehicles involved. As can be noted from the table, in 84 percent of all the accidents investigated, the vehicles were both heading in the same direction and the accidents were classified as a rear-end collision or a same-direction sideswipe. Pertinent to this phase of the study is the information presented in table 8, that in some 17 percent of the accidents, one of the vehicles was reported as not moving immediately preceding the accident.

Auxiliary descriptors.—The emphasis of this phase of the study is directed very specifically toward the speed variation of all traffic compared to the difference in speeds of accident-involved vehicles. However, for each two-vehicle accident which served as an observation, considerable additional information on the accident and the unit of highway was collected. A complete list of the highway, traffic, and environmental variables on which data was available would parallel the descriptions given earlier in table 2. The explanations and list will not be repeated in this phase of the study. The accident variables used here differ in some respects because of the properties of two-vehicle accidents compared to single-vehicle accidents. However, most data on a per vehicle basis is the same as utilized earlier. Averages over all accident observations studied in this phase of the report for selected items are presented in table 9. The data are given separately for urban and for rural areas.

The averages given in table 9 show urban/rural differences generally similar

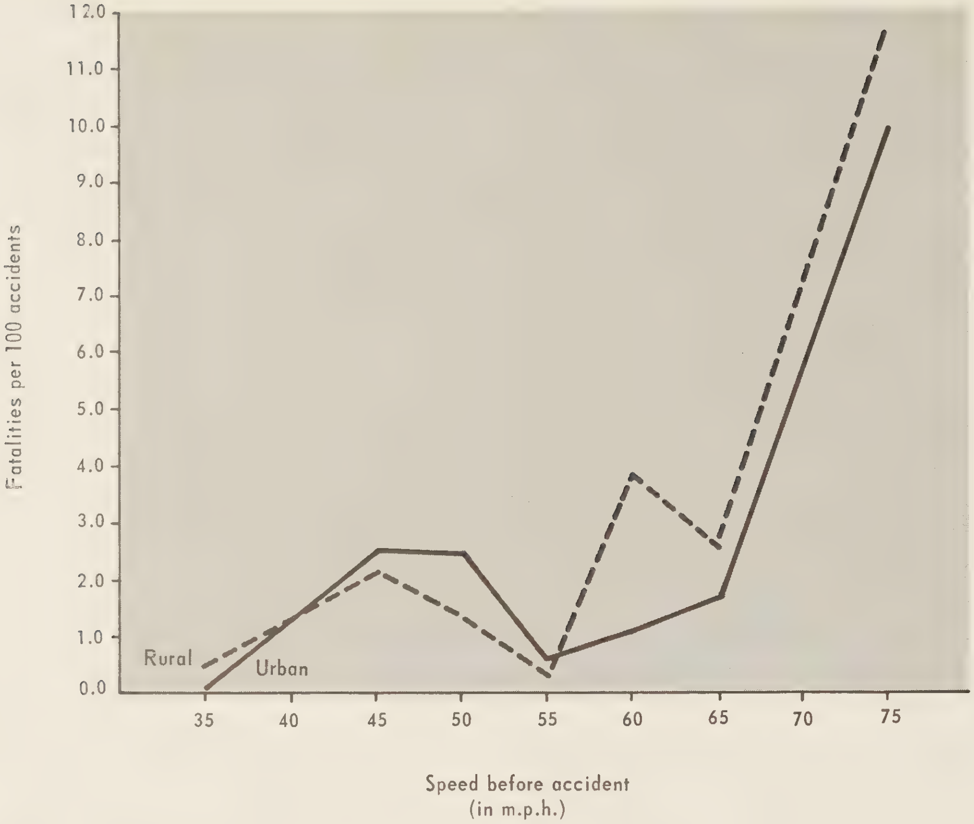


Figure 4.—Average reported fatalities per 100 single-vehicle accidents observed, by speed before the accident for urban and for rural areas.

to those given in table 3 which refers to Phase I of this study. The table 9 data, however, do seem to indicate substantially more traffic in both urban and rural areas. Thus, the two-vehicle accidents seem to occur with greater frequency in high traffic areas than do the single-vehicle accidents reported on earlier. This premise seems logically sound, but is further substantiated in the data by the fact that 40 percent of the two-vehicle accident observations were in urban areas and only 27 percent of single-vehicle accidents occurred in these same areas. Also, 84 percent of all the two-vehicle accidents observed were reported as rear-end collisions or same-direction sideswipes. This would certainly imply the congested traffic conditions more typical of the urban areas.

Further noteworthy comparisons of two-vehicle accident observations with those for single-vehicle accidents concern the accident experience. Table 9 presents injury, fatality, and property damage occurrences per vehicle per accident. The averages are determined for the first and second vehicles combined. The designation in the record of first and second vehicle has no meaning and is simply done to differentiate between the two.

The two-vehicle accident data indicate a much lower injury and property damage rate on a per-vehicle basis. The injury rate per vehicle for all accidents in rural areas was .54 in single-vehicle accidents compared to .41 per vehicle in the two-vehicle accidents. Similarly, the reported amount of property damage per vehicle in two-vehicle accidents in rural areas averages $495 compared to the $988 per vehicle reported for single-vehicle accidents.

The substantial differences in the severity rates per vehicle are, to some extent, due to differences in reporting rates. That is, the less serious accidents are much more likely to be reported when two drivers are involved than in the case of a single driver with no one else to blame. Also, the preponderance of rear-end or same-direction sideswipes as the manner of collision for two vehicles might be a less serious type of accident than the involvements of single vehicles in accidents.

Analysis

The purpose of the second phase of this study is to investigate possible relationships between the variation (or spread) of the speed of all vehicles on the highway compared with the reported speeds or speed differences of accident-involved

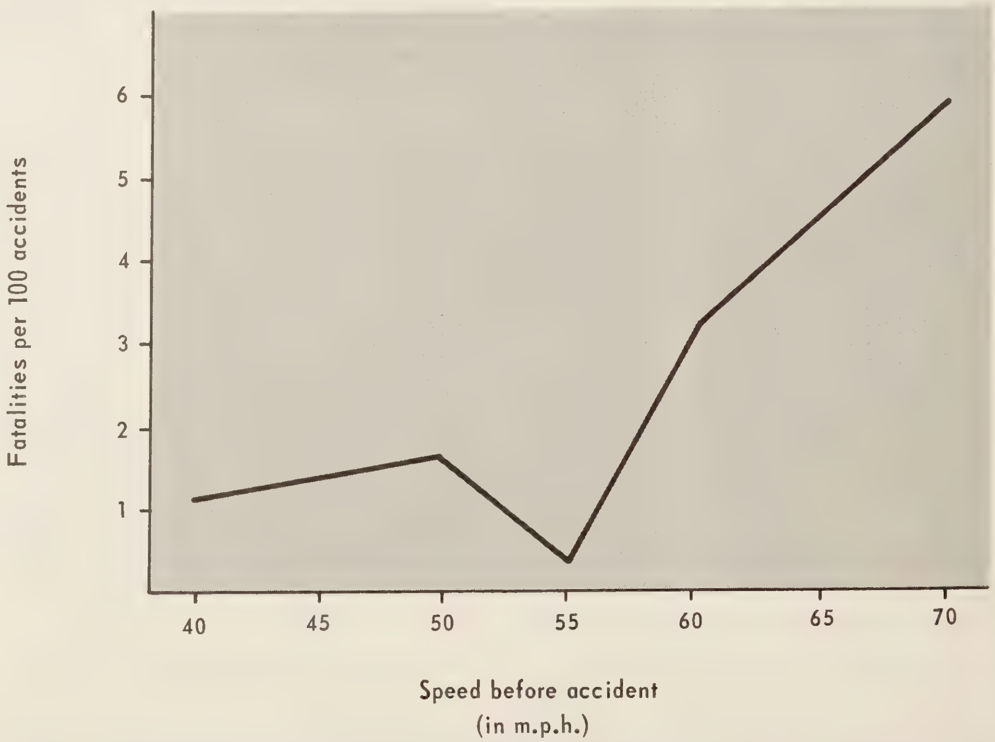


Figure 5.—Average reported fatalities per 100 single-vehicle accidents observed, by speed before the accident.

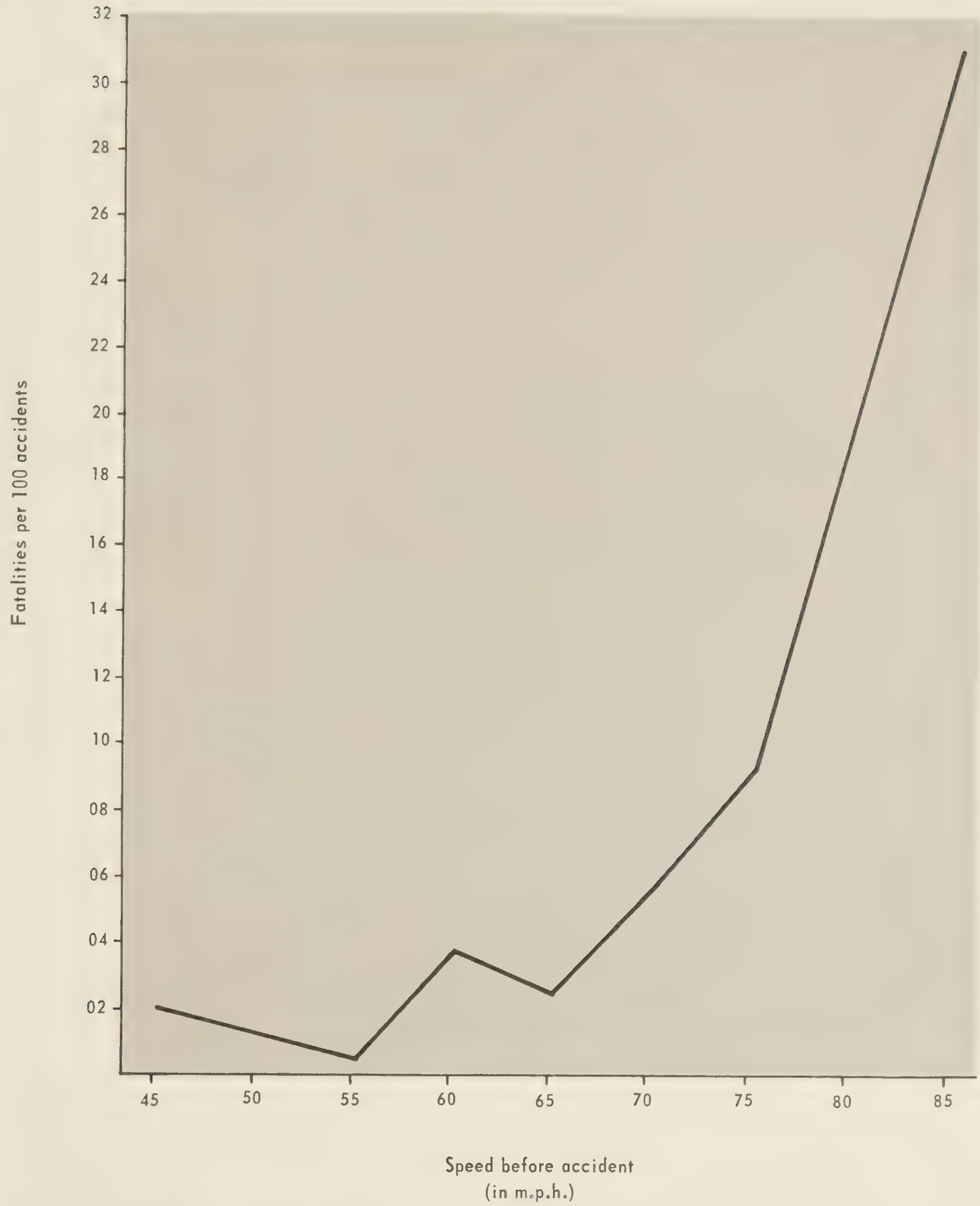


Figure 6.—Average reported fatalities per 100 single-vehicle accidents observed in rural areas by selected speed before the accident.

vehicles. For each mainline section of Interstate highway included in the ISAR–II data base, a relative speed distribution is estimated. That is, the proportion of vehicles traveling in selected speed intervals or groupings is estimated for each section or unit of highway. The methods of estimation vary from State to State and even between locations but the estimates are generally based on actual observations during sample daytime periods. The overall accuracy of these estimates is not known and will not be a matter for study here. The point of interest is that every accident takes place on an identified section of highway with a *known* speed distribution for all vehicles on that section.

It would, of course, be more appropriate for analysis purposes to know the speed distribution of traffic on the highway at the time of the accident. This is impossible to determine in the present case and would require a relatively heavy expenditure of resources to collect such data for future studies. It would seem that if relationships appear to exist with the general speed distribution of daytime traffic, these relationships would be stronger with the speed distribution of traffic at the time of the accident.

In addition to the general speed characteristics of the traffic on the unit of highway, there are the specific speeds of the vehicles involved in an accident. For each vehicle involved directly in an accident, the estimated speed of that vehicle immediately preceding the accident is recorded as part of the accident record. In the present case, two vehicles are involved in each accident and there is, consequently, a speed-before-the-accident for each.

The reported speeds before the accident for vehicles involved in two-vehicle accidents are subject to much the same biases discussed earlier with regard to single-vehicle accidents. However, here there is the additional influence of a second vehicle with occupants, whose collective effects on recorded speeds cannot be judged.

The present analysis will focus on one possible relationship. This involves differences between the reported speeds before the accident of the two involved vehicles. This difference in reported speeds is compared or cross classified with the standard deviation (described below) of the speed distribution of all vehicles to investigate possible relationships. In this analysis, there is a sample point for each accident rather than for each vehicle.

The standard deviation describes the spread or variability of a distribution. In the present case, consistent computation is the important characteristic. The formula used here was

$$s = \sqrt{\frac{\Sigma f_i \ (x_i - \bar{x})^2,}{\Sigma f_i}}$$

Where the f_i are the relative frequencies of the speed distribution and the x_i are the midpoints of the speed intervals or groupings. Also, $\Sigma f_i = 100$ if f_i are percentages and $\bar{x} = \Sigma f_i x_i / 100$.

Analytic results

Variables of interest.—The variables investigated in this analysis are the speed distribution on the highway units and the speeds of the vehicles involved in the two-vehicle accident observations. The average speed distributions on the highway units involved in this phase of the study are presented in table 10 for urban and rural areas separately. Also given in table 10 are the overall arithmetic mean and standard deviations of each average speed distribution. Both the average speed and the dispersion of speeds are slightly less on the urban highway units.

Table 8.—Number and percent of two-vehicle accident observations by type of area, by movement of vehicles for all accidents and same direction accidents

	Urban		Rural		Total	
	Number	Percent of total	Number	Percent of total	Number	Percent of total
All accidents						
Both vehicles moving	221	31	378	52	599	83
One vehicle not moving	69	10	53	7	122	17
Total	290	40	431	60	721	100
Same direction accidents						
Both vehicles moving	181	25	327	45	508	70
One vehicle moving	57	8	42	6	99	14
Total	238	38	369	51	607	84

Table 9.—Average values for selected variables collected in Phase II, by area type

	Average value	
	Rural	Urban
Length of unit ... feet	2,970	1,443
Maximum curvature ... degree	.42	.70
Existence of structure (1=yes, 0=no)	.30	.70
Average daily traffic on unit (in vehicles)	5,700	29,491
In-State passenger cars—daytime ... percent	49	70
Out-State passenger cars—daytime ... do	33	14
Average daytime speed—all vehicles ... m.p.h.	61	59
Occurrences per vehicle per accident		
Number of fatalities	.026	.007
Number of injuries	.41	.33
Amount of property damage ... dollars	495	267

It is interesting to note that the average reported speeds before the accident of the vehicles involved in two-vehicle accidents were 42 m.p.h. and 46 m.p.h. for urban and rural accident locations respectively. Thus, the accident-involved vehicles would seem to be traveling on the average 15–17 m.p.h. slower than the general traffic on the same highway. The extent to which this deviation represents bias in reporting is not known. It will be recalled that average speeds before the accident for single-vehicle accidents were only about 5 m.p.h. below that of the average speed of all daytime traffic on the unit.

Table 11 presents a frequency distribution of two-vehicle accidents by the reported difference in speeds of the involved vehicles. The average speed difference of the involved vehicles is just under 20 m.p.h. for accidents occurring in both urban and rural areas. Although the frequencies are highest for the low speed differences, there are still substantial numbers reported for the higher differences. Almost 10 percent of the speed differences reported for rural area accidents are equal to or greater than 50 m.p.h. In the urban areas, over 10 percent of the accidents reported speed differences exceeding 50 m.p.h. After 10 m.p.h. in urban areas and 20 m.p.h. in rural areas, the reported speed differences occur with relatively constant frequencies to the maximum difference of 60 m.p.h.

Investigation of the accidents which involved only passenger cars or those which resulted only in rear-end and same-direction sideswipes types of collisions or even those where both vehicles were reported as moving reduces the average difference by up to 5–10 m.p.h. However, even in these cases, where more homogeneous subgroups are considered, there are a number of accidents with the very high reported differences. Thus the general distribution of the difference as shown in table 11 is representative of the reported speed differences in two-vehicle accidents.

As a matter of interest, consider the average speed of all involved vehicles of 42 m.p.h. in urban areas and 46 m.p.h. in rural areas. This information combined with the average speed difference of approximately 20 m.p.h. implies that, in two-vehicle accidents, the faster moving vehicle averages about 52 m.p.h. in urban areas and 56 m.p.h. in rural areas. These corresponding averages for the slower moving vehicle are 32 m.p.h. and 36 m.p.h.

Analytic technique.—The investigation of the associations between difference in speeds of involved vehicles with speed variations of traffic on the highway units involved contingency table analysis. This technique utilizes cross classifications of observed frequencies and leads to a test of the hypothesis of independence of the classifications. The technique depends

Table 10.—Average speed distributions of all traffic on highway units with accident observations, including the arithmetic mean and standard deviation of each distribution for urban and rural areas

Speed group	Average percent of vehicles	
	Urban	Rural
Less than 40 m.p.h.	1.4	.7
40–49 m.p.h.	11.2	8.1
50–59 m.p.h.	41.2	35.8
60–69 m.p.h.	8.5	43.0
70–79 m.p.h.	7.3	11.4
80 m.p.h. or greater	.4	1.0
Arithmetic mean	59	61
Standard deviation	7.6	7.7

only on the assumption that the observations are selected independently. There are no assumptions on the underlying population distributions.

The test statistic employed in contingency table analysis is the Chi-square (X^2) statistic. The value in a particular analysis is computed as,

$$X^2 = \sum \frac{(f_o - f_e)^2}{f_e}$$

where f_o and f_e are the observed and expected frequencies, respectively, and the summation is taken over all observed cells. The expected frequencies are computed under an independence assumption so that the higher the computed value of X^2, the less likely is independence. If the classification relationships observed are truly independent, the computed X^2 value follows a specified distribution which is tabled. A comparison of the computed value with appropriate tabled values indicates the likelihood of the observed results under the independence hypothesis. This likelihood is ordinarily stated in terms of significance at the .01 or .05 level. That is, if the likelihood is less than, say, .05, that the observed result could have resulted from chance or sampling variation alone, then the result is said to be significant at the .05 level.

With regard to the present analysis, some departure from the underlying independence assumption is to be noted. The observed frequencies refer to number of accidents. These observations are not completely independent in the required sense of random selection. Two or more accidents may have occurred on the same section of highway either in the same year or not. This departure from the independent selection assumption is not considered sufficiently serious to detract from the analytical results. There is little evidence that a strong association exists between characteristics of the roadway between interchanges of the Interstate System and accidents on that roadway. Thus, even though some of the accidents are related by occurrence on the same sections of highway, they are essentially equivalent to independent selection.

Analysis.—The objective of this phase of the study was primarily to investigate relationships between speed differences of the vehicles involved in an accident and the overall speed variation on the corresponding unit of highway.

It has been noted or stated or found in previous research (*3*) that the difference in speed before the accident of two accident-involved vehicles is substantially greater than for two randomly selected vehicles traveling on the same section of highway. This finding is reinforced in the present study.

If it is assumed that the average speed distributions on the included highway units is normal, then valid estimates of the mean and standard deviation of the difference in speeds between two randomly selected vehicles can be made. The distribution of the range and its relation to the standard deviation in samples of size two (under normality assumptions) is well documented and tabled (*4*). These estimates can then be used to indicate the deviation of the observed speed difference from the expected speed difference.

The estimated standard deviation of the average speed distribution in both rural and urban areas has an approximate value of 7.7. This leads to an expected speed difference of two randomly selected vehicles at 8.6 m.p.h. The observed speed differences between accident-involved vehicles was seen to be only slightly less than 20 m.p.h. Hence, speed differences for two vehicles involved in an accident is, on the average, 11.4 m.p.h. greater than for two randomly selected vehicles. The magnitude of the excess is almost twice the standard error even for single observations. Thus, in the present investigation, the likelihood of the greater speed difference for accident-involved vehicles being due to sampling variation alone is practically nil. This leads to the almost certain conclusion that the average difference in speeds before the accident of two vehicles involved in an accident is somewhat greater than this average difference between speeds of pairs of other vehicles on the same units of highway.

The background of higher speed differences being associated with accidents, which is substantiated here, led to Phase II of the present analysis. This phase was designed to determine if a relationship existed between speed difference between accident-involved vehicles and speed variation (as indicated by the standard deviation) on the unit of highway. The existence of a direct relationship could then lead to the use of higher speed variation on sections of highway as a

Table 11.—Number and percent of two-vehicle accident observations by reported difference between speeds before the accident, by area type

Reported speed difference (m.p.h.)	Number of Accidents			
	Urban		Rural	
	Number	Percent	Number	Percent
0	72	24.8	54	12.5
5	33	11.4	70	16.2
10	52	17.9	69	16.0
15	14	4.8	49	11.4
20	21	7.2	49	11.4
25	8	2.8	26	6.0
30	12	4.1	22	5.1
35	7	2.4	13	3.0
40	14	4.8	16	3.7
45	12	4.1	12	2.8
50	15	5.2	14	3.2
55	16	5.5	15	3.5
60	14	4.8	22	5.1
	290	100	431	100

prediction of higher multiple-vehicle accident frequency which could be followed by operational strategies to lessen the impact of the high variability in the vehicle speed pattern.

Contingency table analysis was utilized to analyze cross-tabulated frequencies for several different breakdowns of the two-vehicle accident observations. The cross tabulations involved two-way groupings by standard deviation of the average speed distribution in one direction and speed difference between accident-involved vehicles in the other direction. Investigations were made for urban and rural data separately and for subgroups of the data restricted as follows:

- Passenger cars and four-wheel trucks only.
- Rear-end or same-direction sideswipes only.
- Both cars moving only.

In none of the analyses was there evidence of a significant result. In other words, there was no evidence to contradict the hypothesis of independence between speed difference of accident-involved vehicles and speed variation on the highway. Hence, even though accident-involved vehicles have speed differences higher than other pairs of vehicles on the same sections of highway, it does not seem that, for accident-involved vehicles, higher speed differences are associated with sections of highway with higher speed variation or standard deviation of speed.

An example of a base table for one of the contingency table analyses is given as table 5. The two computed chi-square values resulting from the urban and rural parts of the table are

(1) Urban: $X^2 = 7.65$
(2) Rural: $X^2 = 6.67$

In both cases, the tabled X^2 value for significance at the .05 level is 21. Computed values as large or larger than these, under independence, would occur with probability approximately .80.

REFERENCES

(*1*) Julie Anna Cirillo, Stephen K. Dietz, and Richard L. Beatty, "Analysis and Modeling of Relationships between Accidents and the Geometric and Traffic Characteristics of the Interstate System," *U.S. Department of Transportation, Federal Highway Administration,* August 1969.

(*2*) A. M. Mood and F. A. Graybill, "Introduction to the Theory of Statistics," 2d ed., 1963, p. 147.

(*3*) David Solomon, "Accidents on Main Rural Highways," *U.S. Department of Commerce, Bureau of Public Roads,* July 1964.

(*4*) E. S. Pearson and H. O. Hartley, "The Probability Integral of the Range in Samples of *n* observations from a Normal Population," *Biometrika,* 32, 1942.

PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH,

is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Effective January 1, 1973, this publication will be sold at $4.50 per year ($1.25 additional for foreign mailing) or $1.25 per single copy. Subscriptions are available for 1-, 2-, or 3-year periods. (See inside front cover.)

Slope-tapered inlet in North Carolina.

Implementation of Improved Culvert Inlet Concepts

Reported by JEROME M. NORMANN,
Highway Engineer,
Hydraulics Branch,
Bridge Division

OFFICE OF ENGINEERING

RESEARCH conducted for the Offices of Research and Development of the Federal Highway Administration (FHWA) by the National Bureau of Standards (NBS) proved that the capacity of some culverts can be increased significantly by improving the hydraulic flow conditions at the culvert inlet. The results of the culvert research are contained in a series of seven reports, (*1–7*),[1] produced during the period from 1955 to 1967. The first three reports treat general culvert hydraulics, while improved inlets for pipe and box culverts is the topic of the last four reports.

The research necessarily dealt with a wide range of culvert geometries and detailed hydraulic theory. Some inlet configurations operated well, while others did not meet expectations.

The first step in implementing the research results was the development of a design manual for improved culvert inlets, containing the most advantageous designs in terms of hydraulic efficiency, ease of construction, and minimum maintenance problems. The inception of the FHWA Demonstration Projects Program in 1969 provided an opportunity for a cooperative effort between Region 15 and the Offices of Engineering and Research and Development to produce such a manual and to implement the concepts through Demonstration Project No. 20, "Improved Inlets for Highway Culverts."

Conventional Highway Culverts

A conventional highway culvert is generally defined as one with its invert and roof on a constant slope, and with the same cross sectional area and shape throughout the culvert length. No significant effort is directed at improving the flow conditions at the entrances of these culverts.

In Hydraulic Engineering Circular (HEC) No. 5 (*8*), it is demonstrated that culverts may operate in either inlet control or outlet control. When a culvert operates in inlet control, the entrance restricts the flow, and the barrel could permit the passage of more water. In outlet control, the culvert barrel is acting as the flow restraint, and the inlet is capable of more efficient hydraulic operation.

When a culvert is operating in outlet control, its barrel is generally full, or nearly so, at the design discharge. Friction losses through the barrel are usually much larger than inlet losses. Thus, reduction of the barrel roughness would influence culvert capacity more than inlet improvements.

However, when a culvert operates in inlet control, the contraction at the en-

[1] Italic numbers in parentheses identify the references listed on p. 107.

trance controls the flow, as shown in figure 1, and the full capacity of the barrel is unused. This uneconomical situation of hydraulically unbalanced flow is the target of improved inlet design. The goal is a culvert design, which, at the design discharge, takes the fullest advantage of the barrel capacity, while avoiding undue sophistication of the culvert inlet structure.

Types of Improved Inlets

Three general types of improved inlets —bevel-edged, side-tapered, and slope-tapered—were selected for presentation in the new improved inlet design manual.

Beveled edges (fig. 2) are the least costly inlet improvement, as major structural modifications of the culvert are not required. The bevels are sized in proportion to the barrel dimensions, and various bevel angles may be used. Design charts have been prepared for 45-degree bevels and 33⅓-degree bevels. Bevels improve the entrance flow conditions by reducing the contraction downstream of the culvert face, thereby utilizing more of the available culvert barrel area for the conveyance of the flow. The 45-degree bevels are smaller and easier to construct while the larger 33⅓-degree bevels provide additional hydraulic efficiency but may require structural reinforcement of the culvert headwall.

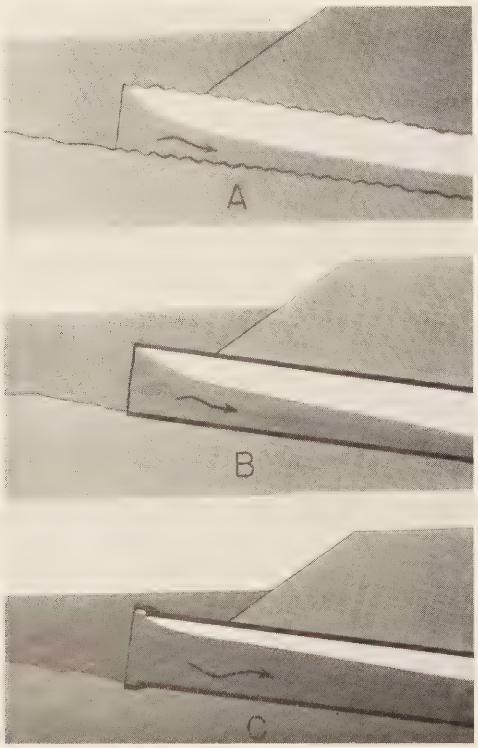


Figure 1.—Entrance contractions at conventional culvert inlets, inlet control.
A.—Thin-edged projecting
B.—Thick-edged projecting
C.—Groove-end projecting

Side-tapered inlets involve a structural modification to enlarge the face area of the culvert. The enlarged face area is transitioned to the culvert barrel by straight tapered sidewalls, and the floor and roof are extensions of the barrel floor and roof. There are two possible control sections—the throat and the face (fig. 3). Inlet control should be at the throat as that section determines the size of the barrel, which is the most expensive component of the culvert. The throat section is very efficient hydraulically, in that the contraction of flow at that section is less than that of any other suggested inlet control section. The face section is simply sized large enough so that it will not control the flow, and it is clear that varying the face size is economically inconsequential. Edge improvements, such as bevels and favorable wingwall angles, will reduce the size of the required face section.

A secondary advantage of the throat section in the side-tapered inlet is that it is lower than the face, which means that for the same headwater pool elevation, more head is applied to the throat control section. In the slope-tapered inlet, shown in figure 4, still more head is applied to the efficient throat control section by concentrating some of the total culvert fall in the inlet structure. As the inlet fall is increased in culverts operating in inlet control, the slope and size of the barrel decrease but the required size of the inlet structure increases. In addition to the face and throat control sections, control could be at a third section, the bend, upstream of the throat. However, following the design recommendations of the new design publication, "Hydraulic Design of Improved Inlets for Culverts," HEC No. 13 (9), eliminates the need to directly consider bend-section control. Design charts are provided for two types of slope-tapered inlets, one with a vertical face and one with a face mitered to the embankment slope.

More head may also be applied to conventional, bevel-edged, or side-tapered inlets by depressing the control section, using some type of sump upstream of the inlet end of the culvert. Some efficient sump configurations are suggested in HEC No. 13.

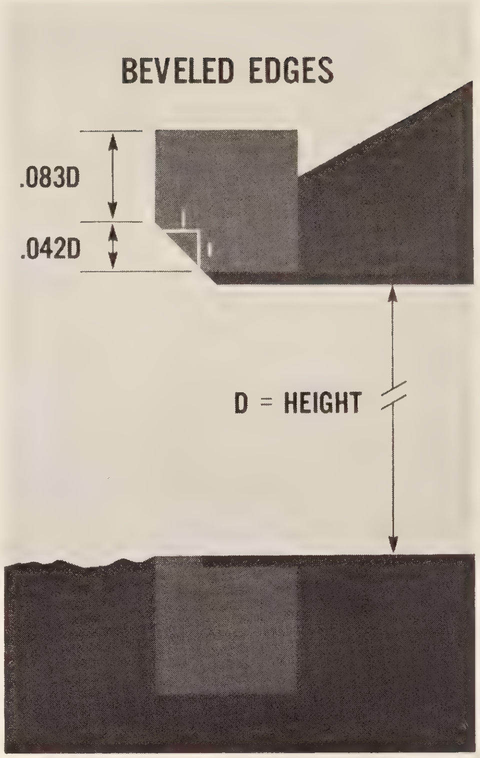


Figure 2.—Beveled edges, 45-degree angle.

Advantages of Improved Inlet Use

Improved inlets, when applied to culverts operating in inlet control, may be used to produce three desirable results: (1) The barrel size of the culvert may be reduced significantly, as shown in figure 5, (2) the capacity of a given barrel size may be increased at a given headwater elevation, as illustrated in table 1, and (3) the headwater required to pass a given discharge through the inlet may be reduced (table 2). All of the examples cited assume sufficient fall over the culvert length to permit utilization of the side- and slope-tapered inlets.

Demonstration Project 20

Demonstration Project No. 20, "Improved Inlets for Highway Culverts," was initiated in the fall of 1970 by the selection of a Technical Advisory Committee and the formulation of a project prospectus. The Committee consists of members from the Offices of Research and Development, Engineering, and Region 15. The prospectus was approved on November 5, 1970. The demonstration project was to consist of three phases. Phase 1 included development of a design manual, a field survey of existing improved inlet

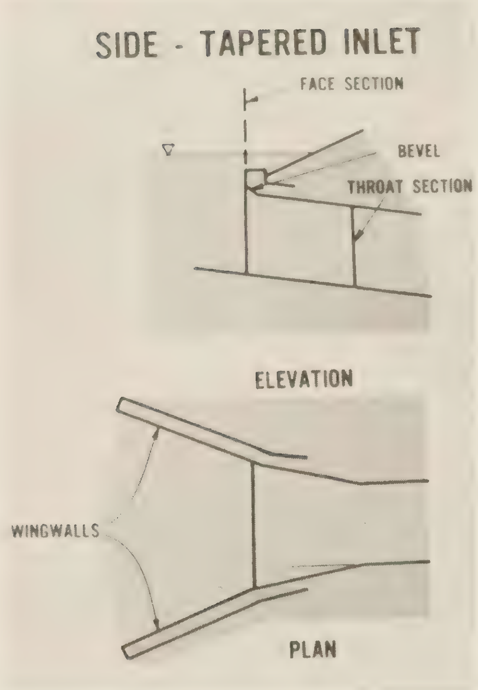


Figure 3.—Side-tapered inlet.

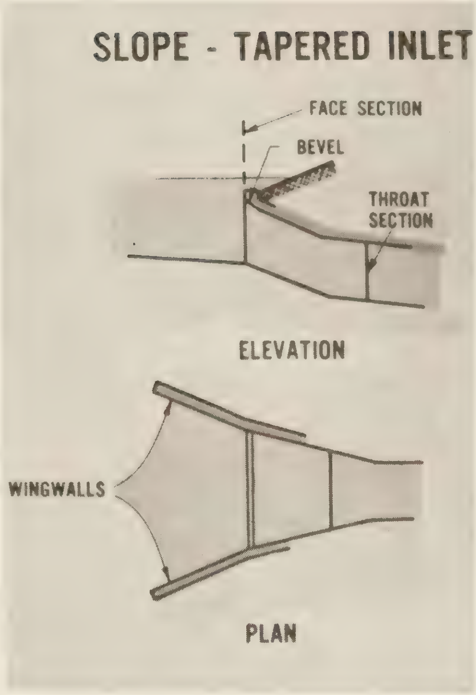


Figure 4.—Slope-tapered inlet.

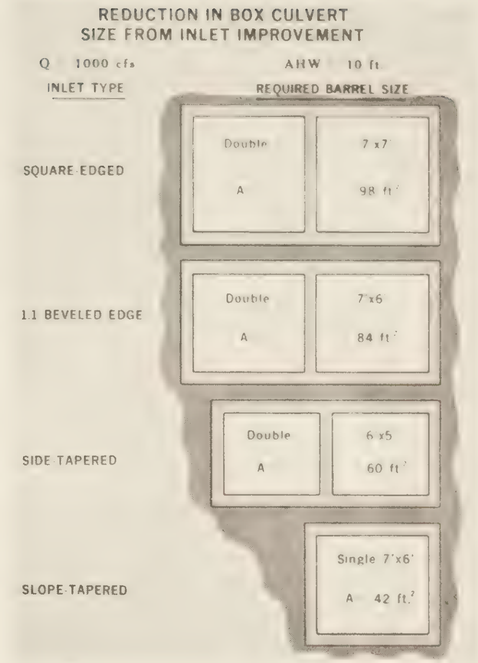


Figure 5.—Reduction in box culvert barrel size due to inlet improvement. Flow = 1,000 cfs, allowable headwater = 10 feet, total culvert fall = 17.5 feet.

installations to demonstrate improved inlet performance and cost effectiveness, and the development of promotional aids for Phase 2. Promotional aids included illustrative artwork and the design and construction of a portable hydraulic flume and models. Phase 2, currently underway, is the presentation of workshops promoting and encouraging use of the improved inlet design concept by the concerned field office. Phase 3 will be the preparation of a final report summarizing the accomplishments of the demonstration project.

Design manual

The new improved inlet design manual, "Hydraulic Design of Improved Inlets for Culverts," HEC No. 13, was first printed in November 1971. Since then, the design procedure has been further evaluated, and a revised edition was issued in August 1972 (*9*).

The publication contains design charts, nomographs, tables, and calculation sheets for culvert design. Use of the recommended design procedure will result in the design best suited to the given site and hydrologic conditions, using improved inlets when justified.

Field survey

The field survey, summarized in Appendix C of HEC No. 13, contains cost information on 66 installations out of the 75 installations reported. The savings estimated by the users amounted to a total of $2,049,000. Individual benefits ranged from $500 to $482,000, with savings greater than $50,000 quite common. It should be noted that the results do not represent a complete survey of all improved inlet installations in the United States, since time and financial constraints prevented some States and installations from being reported in the survey.

The questionnaire posed direct questions as to maintenance problems experienced with the culverts with improved inlets. Of the 75 installations reported,

Table 1.—Comparison of inlet performance at constant headwater for a 6 by 6 foot reinforced concrete box culvert

Inlet type	Headwater	Discharge	Percent improvement
	feet	*c.f.s.*	
Square-edge	8.0	336	0
Bevel-edge	8.0	392	16.7
Side-tapered	8.0	438	30.4
Slope-tapered [1]	8.0	523	55.6

[1] Fall in inlet = 1.5 feet = D/4—minimum fall permitted for slope-tapered inlets.

Table 2.—Comparison of inlet performance at constant discharge for a 6 by 6 foot reinforced concrete box culvert

Inlet type	Discharge	Headwater	Percent reduction
	c.f.s.	*feet*	
Square-edge	500	12.5	0
Bevel-edge	500	10.1	19.2
Side-tapered	500	8.8	29.6
Slope-tapered [1]	500	7.6	39.2

[1] Fall in inlet = 1.5 feet = D/4—minimum fall permitted for slope-tapered inlets.

none had debris problems; eight had some minor sediment build-up with no clogging; and eight had some scour at the outlet. Of the eight with some scour problems, two required corrective action. Of course, the use of conventional culverts at these sites would probably have also required some type of scour protection.

Figure 6.—Portable hydraulic flume.

Promotional aids

The portable hydraulic flume, shown in figure 6, and its improved inlet models were completed in November 1971. The flume has a working length and width of 84 inches and 18 inches, respectively. The maximum flow capacity is about 225 gallons per minute, and its variable slope and flow rate permit the demonstration of a variety of hydraulic conditions and installations. Improved inlet models are available for both circular pipe and rectangular box culverts. Models of conventional bevel-edged, side-tapered, and slope-tapered inlets have been constructed. The flume and models may be disassembled and packed in crates suitable for shipping.

In addition, some basic hydraulic principles in the design of storm drain grate inlets and the advantages of spur dikes at bridge abutments can be demonstrated in the flume by the use of other models, which are available during the flume demonstrations.

Visual aids, including new 35 millimeter slides on conventional and improved inlet culvert hydraulics, posters, and handouts for a variety of presentation formats have been prepared. As the need develops in meeting the desires of the field offices, new visual aids are obtained, and the presentations are in a continual state of revision and improvement.

Workshops

The FHWA regional offices are encouraged to hold regional hydraulic conferences first, in order to introduce the design concepts to division office and State personnel, who would then arrange subsequent meetings on the State level. Shortly thereafter, the demonstration would go into each interested State to present the workshop to the division office and State designers and administrators, consultants, and local government representatives.

The typical workshop comprises two lectures, one on conventional culvert hydraulics and the other on improved inlets; a hydraulic demonstration with the portable hydraulic flume and models; an introduction to the new culvert design procedure; and a problem solving session wherein attendees actually perform the calculations for an improved inlet design.

Thus far, the workshop has been presented to four regional meetings, 11 State meetings, and four professional meetings. About 1,300 people have viewed the demonstration through September 1972. Not all of the meetings were full demonstrations, as workshops are tailored to the news and desires of the attendees. Some meetings are of a general informational nature, while others include the detailed design sessions.

Benefits

The field survey of improved inlet installations, mentioned previously, indicated the magnitude of the savings which could be realized through the use of improved culvert inlet design. Figure 7 shows a side-tapered structure near Lexington, Va. In this structure, a single 7 by 7 foot barrel was used instead of a conventional double-barrel 6 by 6 foot culvert 1,130 feet long. The estimated savings amounted to $42,000, or 25 percent of the culvert cost.

Figure 8 shows a double-barrel 12 by 12 foot concrete box culvert over 2,700 feet long near Knoxville, Tenn. Use of a side-tapered inlet on this structure reduced the required barrel size from a conventional triple-barrel 13 by 14 foot box culvert, resulting in the largest saving reported in the survey, $482,000, or about 39 percent of the conventional culvert cost. Figures 9 and 10 show a structure near Manchester, Tenn., where a side-tapered inlet was used to increase the capacity of an existing culvert, rather than replacing the structure or building an additional barrel. A slope-tapered inlet structure is illustrated in figures 11, 12, and 13. This structure permitted a barrel size reduction from 10 by 8 feet to 6 by 6 feet, with a savings of $13,000, or 54 percent of the culvert cost.

Most of the above designs were accomplished using the NBS research reports, a tedious procedure due to the detail and range of designs contained in those publications. The availability of a new design manual containing a systematic, logical, and concise culvert design procedure will lead to the use of many more improved inlets on highway culverts at appropriate sites, with savings many times those derived in the past.

Figure 7.—Side-tapered culvert near Lexington, Va.

Although the demonstration project workshops have been underway for less than 1 year, results are already being realized. States which have been designing improved inlets of various configurations are accepting the standardized designs in the new manual. In many cases, the new designs are less complex than the designs the States have been using without any significant sacrifice of the benefits of improved inlet efficiency.

Some States that have not used improved inlets in the past are accepting at least some of the new designs. It is expected that as the advantages of improved inlet usage become more apparent through field experience with the structures, the more sophisticated concepts will be accepted and used where applicable.

Figure 8.—Side-tapered culvert near Knoxville, Tenn.

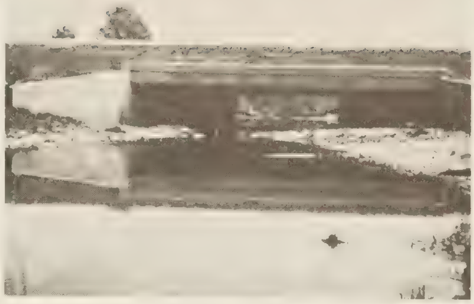


Figure 9.—Double-barrel, side-tapered culvert near Manchester, Tenn.

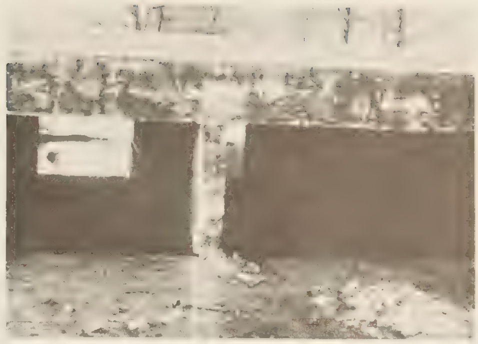


Figure 10.—Outlet end of structure in figure 9.

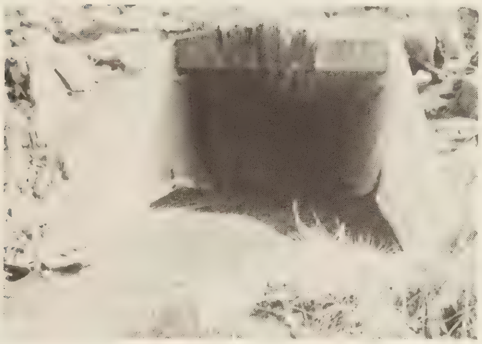


Figure 11.—Slope-tapered inlet structure constructed for the Park Service near Bryson City, N.C.

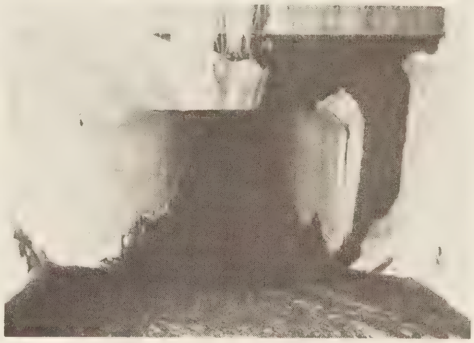


Figure 12.—Close-up of structure in figure 11, showing bend and throat sections.

Figure 13.—View from inside of structure in figure 11, showing straight-line taper from throat to face of inlet.

BIBLIOGRAPHY

(*1*) French, John L., "First Progress Report on Hydraulics of Short Pipes, Hydraulic Characteristics of Commonly Used Pipe Entrances," *National Bureau of Standards Report 4444,* Washington, D.C., December 1955.

(*2*) French, John L., "Second Progress Report on Hydraulics of Culverts, Pressure and Resistance Characteristics of a Model Pipe Culvert," *National Bureau of Standards Report 4911,* Washington, D.C., October 1956.

(*3*) French, John L., "Third Progress Report on Hydraulics of Culverts, Effect of Approach Channel Characteristics on Model Pipe Culvert Operation," *National Bureau of Standards Report 5306,* Washington D.C., June 1957.

(*4*) French, John L., "Fourth Progress Report on Hydraulics of Culverts, Hydraulics of Improved Inlet Structures for Pipe Culverts," *National Bureau of Standards Report 7178,* Washington, D.C., August 1961.

(*5*) French, John L., "Fifth Progress Report on Hydraulics of Culverts, Nonenlarged Box Culvert Inlets," *National Bureau of Standards Report 9327,* Washington, D.C., June 1966.

(*6*) French, John L., "Sixth Progress Report on Hydraulics of Culverts, Tapered Box Culvert Inlets," *National Bureau of Standards Report 9355,* Washington, D.C., June 1966.

(*7*) French, John L., and Bossy, Herbert G., "Seventh Progress Report on Hydraulics of Culverts, Tapered Box Culvert Inlets with Fall Concentration in the Inlet Structure," *National Bureau of Standards Report 9528,* Washington, D.C., July 1967.

(*8*) Herr, Lester A., and Bossy, Herbert G., "Hydraulic Charts for the Selection of Highway Culverts, *Hydraulic Engineering Circular No. 5,* U.S. Department of Commerce, Bureau of Public Roads (now Department of Transportation, Federal Highway Administration), Washington, D.C., December 1965.

(*9*) Harrison, L. J., Morris, J. L., Normann, J. M., and Johnson, F. L., "Hydraulic Design of Improved Inlets for Culverts," Hydraulic Engineering Circular No. 13, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., August 1972.

Fatal Accidents on the Interstate System, 1968-71

OFFICE OF TRAFFIC OPERATIONS

Reported by BENJAMIN V. CHATFIELD, Highway Engineer, and HAROLD R. HOSEA, Accident Record Analyst, Traffic Performance and Analysis Division

Introduction

THE National System of Interstate and Defense Highways is the safest major highway system in the world. Fatal accident rates for the Interstate System are not much more than half the rates for non-Interstate highways in the United States (*1*).[1] Yet, though both Interstate and non-Interstate fatal motor-vehicle traffic accident rates are declining, the rapid growth in travel volume on the Interstate System as the System nears completion leads to increasing numbers of fatal accidents on Interstate highways. In recognition of this problem, the State highway departments have been collecting police reports of fatal accidents on the Interstate System. These reports are forwarded to the Federal Highway Administration and are being studied by both State and Federal highway officials in the belief that a better understanding of the nature of fatal accidents will lead to the development of more effective countermeasures.

The fatal accidents discussed in this article are accidents which have occurred on Interstate highways in the through lanes, on interchange ramps, or at the points where ramps join with roads or streets on other systems. Accidents on frontage roads have been excluded except where the frontage roads meet with ramps carrying traffic to or from the through lanes of Interstate highways.

Description of Data

In the 4-year period from 1968 through 1971, there were about 13,800 fatal motor-vehicle traffic accidents on the Interstate System. Police investigation reports on 12,387 of these accidents—almost 90 percent of the total—have been coded to permit analysis of various relationships among elements of the accident data. Since the accidents for which no reports were received were distributed widely among many reporting jurisdictions, it seems reasonable to assume that the reports in the group analyzed are a reliable sample of reports for all fatal accidents on Interstate highways.

It must be recognized that during any accident study there may be substantial differences between the actual events and the images of those events which are re-created from investigators' reports. Some of the information in the Interstate accident reports is incomplete, some is based on speculation or on the faulty observation or memories of witnesses, and some on incorrect reasoning. To some extent, reporting may be influenced by emphasis on particular elements of the accident picture, such as the part played by alcohol. While about four out of five fatal accident reports indicate whether the driver considered responsible had been drinking, this sort of information is

[1] Italic numbers in parentheses refer to the references listed on page 118.

given for less than half of the accidents in some States and more than 90 percent of the accidents in others.

Generally, fatal accidents on sections of Interstate highway in rural areas are reported by State police while in urban areas local officers are more often involved. The State officers who investigate fatal motor vehicle accidents tend to have more training and experience in this field and, as a group, prepare more complete reports. Whether a State or local police officer is responsible for a report, however, investigation often suffers from a low priority during the period immediately after an accident—the officer at the scene of the accident being most immediately and necessarily concerned with care of those who may be injured, with prevention of further injury or death, and with restoration of normal traffic flow.

Classification of accidents

The establishment of accident classifications for this analysis was determined largely by the availability of information in the fatal accident reports. After the initial and obvious separation of single-vehicle accidents from multiple-vehicle accidents, further classification in a single-vehicle accident included whether the vehicle left the road, overturned, or struck a fixed object, bicycle, pedestrian or parked vehicle. When a pedestrian was involved, he was classified either as a trespasser—since pedestrians are not ordinarily permitted on Interstate highways—or as a non-trespasser, to cover those cases where there might be a legitimate reason for being on foot on the highway—where passengers left disabled vehicles, for example. For multivehicle accidents, the primary distinction was among rear-end, head-on, broadside, and sideswipe collisions, with some secondary distinctions such as the presence of wrong-way operation in head-on accidents.

In all, 29 accident types were identified. These have been combined, as in table 1, to summarize the data in groups large enough for percentage distributions to be meaningful.

In addition to the classification by accident type, data have been sorted by driver, vehicle and environmental characteristics to determine how these characteristics are related to each other and to the types of fatal accident which occur on the Interstate System. Some of the results of this sorting and analysis appear in the tables presented in this article.

Assignment of responsibility

Most motor vehicle accident reports contain information which supports a distinction between drivers responsible for the accidents and those who become involved through no fault of their own. For this analysis, responsibility has been assigned to one driver in each accident. This assignment, sometimes made on quite tenuous grounds, implies no legal responsibility and may occasionally do the named driver some substantial injustice, as when an accident is clearly caused by a pedestrian or when two or more drivers are equally at fault. The assignment of responsibility, while imperfect, appears to be of considerable value in tracing the factors which contribute most to situations in which accidents are likely to occur.

In single-vehicle fatal accidents, responsibility has been assigned in all cases to the driver of the one moving vehicle involved. Assignment of responsibility in multivehicle fatal accidents is based on review of the individual accident reports, with particular attention to narrative descriptions and diagrams of the accidents.

Table 1.—Fatal accidents on completed sections of the Interstate System, 1968–71—accident types, fatalities, injuries, and property damage

Type of accident	Accidents			Fatalities		Injuries		Property damage	
	Number	Percent		Total	Per accident	Total	Per accident	Total ($1,000)	Per accident ($)
		Total	Subgroup						
Total accidents, all types	12,387			14,953	1.21	13,979	1.13	37,705.2	3,044
Single vehicle:									
Ran off road	6,404	51.8	78.0	7,381	1.15	5,348	0.84	16,287.6	2,543
Overturn on road	149	1.2	1.8	160	1.07	137	0.92	327.1	2,195
Collision with parked vehicle	445	3.6	5.4	545	1.22	538	1.21	1,763.9	3,964
Pedestrian:									
Persons outside their vehicles	315	2.5	3.8	331	1.05	46	0.15	77.6	246
Trespassers	748	6.0	9.1	759	1.01	69	0.09	163.3	218
Total pedestrian	1,063	8.5	12.9	1,090	1.03	115	0.11	240.9	227
Other [1]	152	1.2	1.9	166	1.09	96	0.63	264.1	1,738
Total single vehicle	8,213	66.3	100.0	9,342	1.14	6,234	0.76	18,883.6	2,299
Multiple vehicle:									
Rear-end collision	1,856	15.0	44.5	2,243	1.21	3,157	1.70	9,382.7	5,055
Head-on collision:									
Wrong-way driver	626	5.1	15.0	1,019	1.63	1,030	1.65	2,399.0	3,832
Vehicle from opposing lanes	825	6.6	19.8	1,283	1.56	2,059	2.50	3,879.4	4,702
Other [2]	72	0.6	1.7	108	1.50	162	2.25	353.7	4,913
Total head-on collision	1,523	12.3	36.5	2,410	1.58	3,251	2.13	6,632.1	4,355
Broadside collison	300	2.4	7.2	365	1.22	595	1.98	1,058.6	3,529
Sideswipe	495	4.0	11.8	593	1.20	742	1.50	1,748.2	3,532
Total multiple vehicle	4,174	33.7	100.0	5,611	1.34	7,745	1.86	18,821.6	4,509

[1] Primarily, vehicles that struck other objects or non-motor vehicles on the road, and accidents in which occupants fell from vehicles.

[2] Primarily out-of-control vehicles which reversed directions without changing lanes.

Elements of Fatal Accidents on the Interstate System

Environment

One of the relevant elements in any accident analysis is the time when the accident occurred, and this analysis of Interstate fatal accidents is no exception. Accidents occur throughout the day and week in patterns that do not necessarily correspond with variations in traffic volume. As shown in figure 1, fatal accidents peak on the weekend—Friday through Sunday—but the pattern for single-vehicle accidents differs from that for multiple-vehicle accidents. The single-vehicle accident peak is largely a Saturday-Sunday peak while for multiple-vehicle accidents the peak is on Friday and Saturday.

Distribution by hour of the day is shown in figure 2. For both single-vehicle and multiple-vehicle accidents, there are peaks between 4 and 5 p.m. and between 11 p.m. and 3 a.m. For multiple-vehicle accidents the two peaks are at about the same level; the night peak is much higher than the afternoon peak for single-vehicle accidents. An additional difference between the two types of accidents is an evening peak—from 7 to 9 p.m.—that occurs only for single-vehicle accidents.

With 4 years of data as a base, significant results also appear in a distribution by hour of the week. Dividing the study period into 168 parts (7 days $\times$ 24 hours) gives a better picture of events than is available when, for example, the early morning hours of Tuesday and Saturday are combined as in figure 2. During 1968-71 an average of 49 fatal single-vehicle accidents and 25 fatal multivehicle accidents occurred in each of the 168 hourly segments. Both single-vehicle and multivehicle accidents peaked at nearly three times the average hourly figures between 2 and 3 a.m. on Saturday morning. Single-vehicle accidents peaked again 24 hours later at the same level but multivehicle fatal accidents, which also peaked between 2 and 3 a.m. on Sunday morning, rose to less than twice the average hourly figure. While over two-thirds of the fatal single-vehicle accidents which took place on Sundays happened before 6 a.m., only 54 percent of the multivehicle accidents did so. Further study of accident patterns by hour of the week is planned.

Closely related to time are light conditions. Over half of all Interstate fatal accidents occurred during the hours of darkness, but accidents were not uniformly distributed either by time (fig. 2) or by type (table 2) through this period. Only about one quarter of the pedestrian accidents occurred in daylight. Head-on collisions involving wrong-way drivers also typically occurred at night—only one of four occurred in daylight—while head-on collisions in which a vehicle crossed the median into oncoming traffic occurred during daylight hours about two-thirds of the time. The difference between the times of occurrence of the two types of head-on collison appears to be a function of elements other than light conditions. For example, it is difficult for a driver to operate a vehicle in the wrong direction during periods of heavy traffic which more commonly occur during daylight hours. During these same periods, vehicles which cross the median are more likely to collide with oncoming vehicles simply because there are more oncoming vehicles.

Weather conditions have significant effects on the distribution of accident types. Of all Interstate fatal accidents, about 81 percent occur in clear or cloudy weather, 16 percent in rain or snow and 3 percent in fog. The proportion of rear-end collisions in fog is about 5 percent, substantially above normal. Perhaps the most dramatic impact of weather relates to cross-median head-on collisions, 38 percent of which occur in rain or snow. The percentage of pedestrian accidents during rainy or snowy periods is only about half the normal percentage, reflecting the tendency of pedestrians to stay under cover in this type of weather.

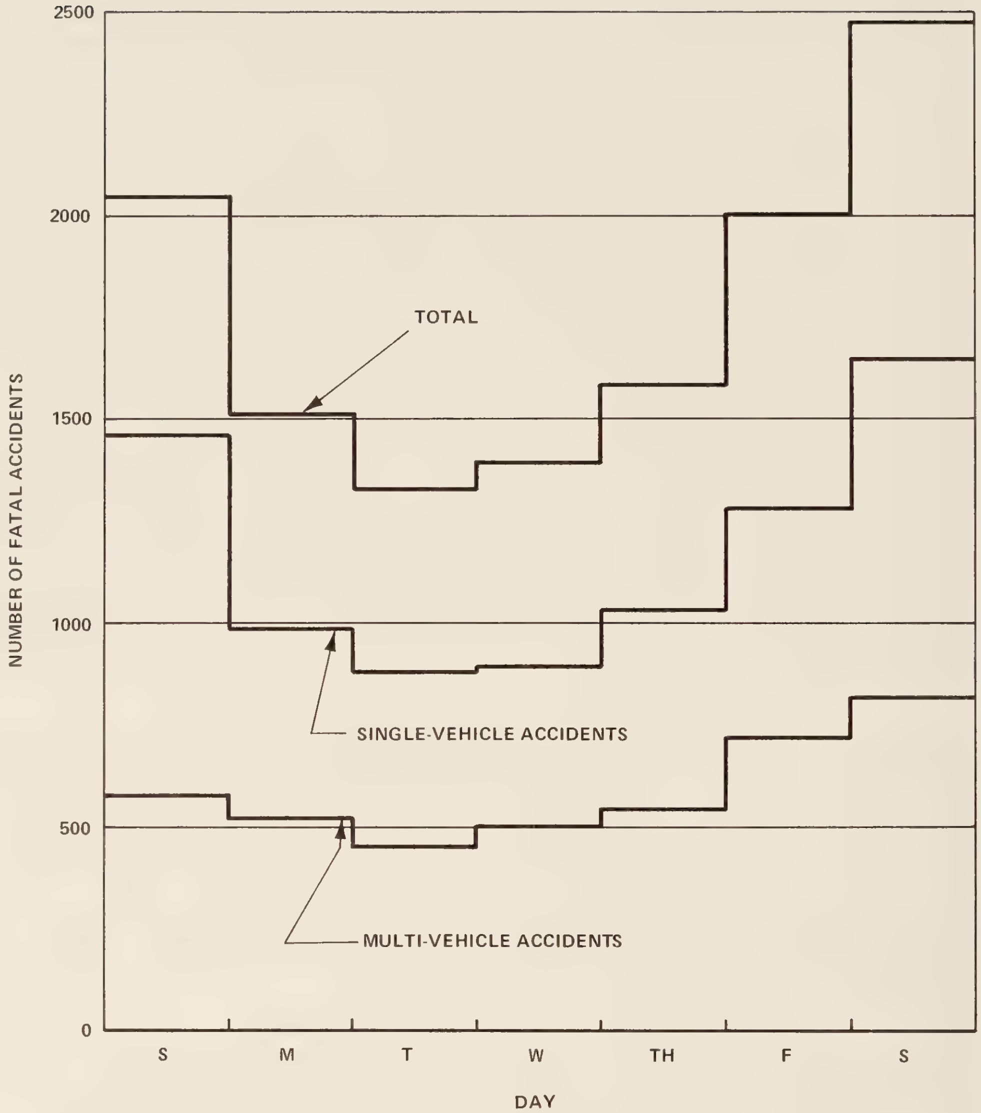


Figure 1.—Fatal accidents on the Interstate System, 1968-71, by day of occurrence.

It is interesting that wrong-way driving is less of a problem in bad weather; only about 9 percent of wrong-way, head-on collisions take place in rainy or snowy weather.

Accident patterns are related to wet or icy pavements, of course, in much the same way as they are related to weather. About 40 percent of cross-median head-on fatal accidents, for example, occur on wet, icy or snowy pavements, while only 21 percent of all fatal accidents occur under these conditions. Accidents in which single vehicles run off the road, which would appear to be triggered by much the same conditions as cross-median head-on accidents, take place when pavements are dry in almost four out of five cases.

More than 78 percent of all Interstate fatal accidents occurred on highway sections reported to be straight. The principal exception was in the case of single-vehicle ran-off-road accidents, but even for this type of accident over 70 percent occurred on straight highways. On the other hand, over 90 percent of rear-end collisions occurred on sections of highway with no appreciable curvature. According to the reports of accident investigators, almost three-quarters of the accidents on straight highways were on relatively level sections while this was true for less than half of the accidents on curves.

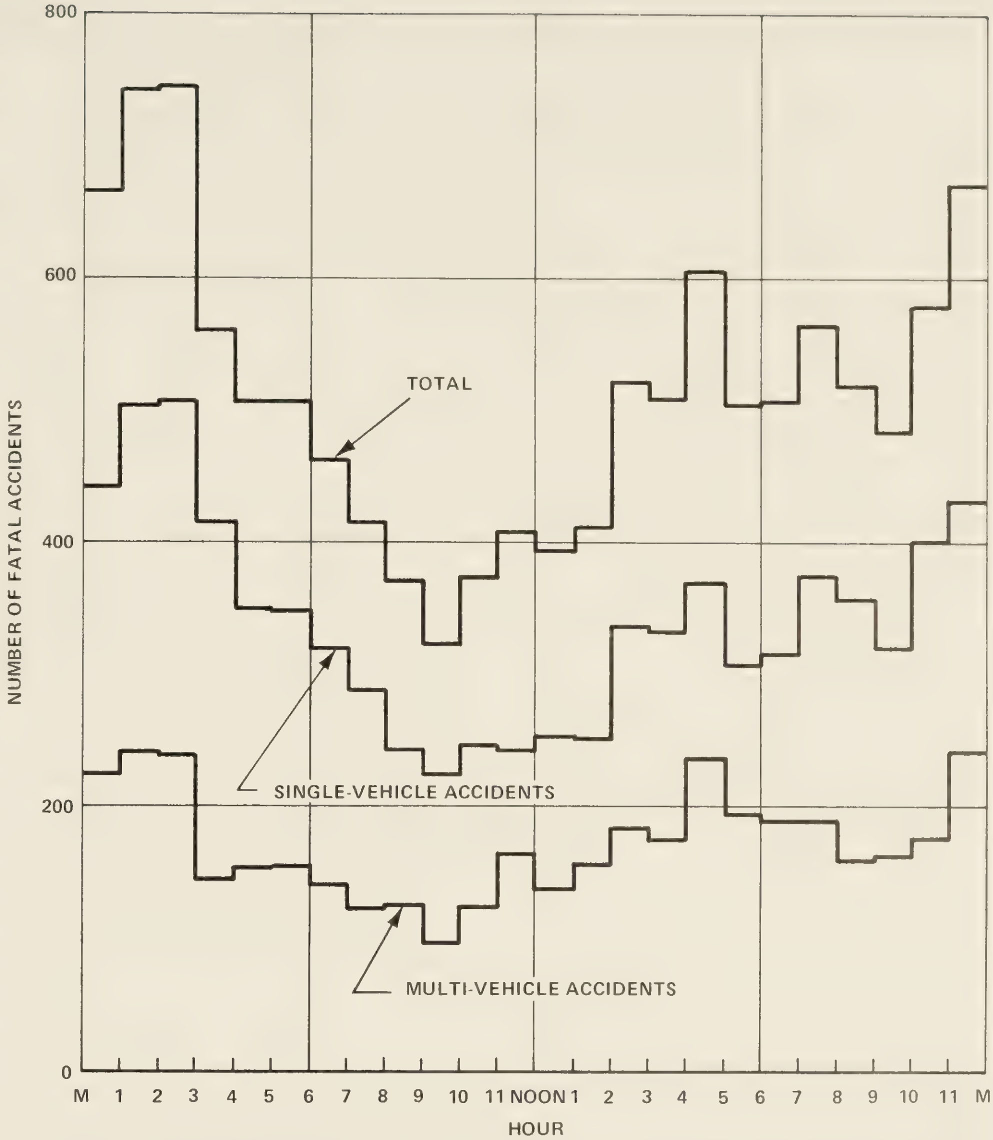


Figure 2.—Fatal accidents on the Interstate System, 1968-71, by hour of occurrence.

Vehicles

Of the vehicles operated by the drivers considered responsible for fatal motor vehicle accidents on the Interstate System from 1968 through 1971, 80 percent were passenger vehicles and 20 percent were property-carrying vehicles; the relative exposure of these two types of vehicles, in vehicle-miles, is roughly the same (tables 3 and 4). Drivers of property-carrying vehicles have been responsible for an increasing share of fatal accidents every year. This share went up from 18.6 percent in 1968 to 22.3 percent in 1971. Much of the increase appears to stem from an increase in the proportion of panel and pickup trucks in single-vehicle, ran-off-road accidents.

In comparing types of fatal accidents (table 4) with the amount of travel for each type of vehicle (table 3), one of the more striking imbalances relates to the involvement of tractor-trailer combinations in rear-end collisions. In almost 20 percent of these collisions a tractor-trailer driver has been classified as responsible, although these vehicles account for less than 10 percent of the vehicle-miles traveled on Interstate highways.

Of the fatal Interstate accidents for which drivers of passenger vehicles were responsible, slightly more than two-thirds were single-vehicle accidents. While this proportion has remained relatively constant, the nature of single-vehicle accidents appears to be changing. The percentage of ran-off-road accidents is declining and the percentage of pedestrian accidents is rising with respect to both the number of single-vehicle accidents and the total number of fatal accidents on Interstate highways (table 5). The involvement of property-carrying vehicles in pedestrian accidents has become increasingly more common; pedestrian accidents constituted 11 percent of the fatal accidents for which drivers of property-carrying vehicles were considered responsible during the 4-year period.

Drivers

In almost a third of the 1968-71 accidents studied, the driver considered responsible for the accident was under 25 years old (table 6). The involvement of this age group did not increase during the 4-year period, but it is too early to tell whether there is a significant downward trend. Similarly, drivers over 75 have been responsible for an increasing share of fatal accidents but it is not yet clear whether this is a trend or random variation.

The physical condition and sobriety of drivers responsible for fatal accidents are

Table 2.—Fatal accidents on completed sections of the Interstate Systems, 1968–1971—accident types and light conditions

Type of accident	Total	Daylight	Light condition: Darkness: Total	Darkness: Unlighted	Darkness: Lighted	Dawn or dusk
Total accidents, all types:						
Number	12,387	5,390	6,420	5,160	1,260	577
Percent	100	43	52	42	10	5
Single vehicle:						
Number	8,213	3,498	4,322	3,435	887	393
Percent	100	42	53	42	11	5
Ran off the road:						
Number	6,404	2,927	3,160	2,487	673	317
Percent	100	46	49	39	10	5
Pedestrian:						
Number	1,063	258	764	608	156	41
Percent	100	24	72	57	15	4
Multiple vehicle:						
Number	4,174	1,892	2,098	1,725	373	184
Percent	100	45	50	41	9	5
Rear-end collisions:						
Number	1,856	743	1,029	853	176	84
Percent	100	40	55	46	9	5
Head-on collisions:						
Number	1,523	722	745	613	132	56
Percent	100	47	49	40	9	4
Wrong-way driver:						
Number	626	159	450	386	64	17
Percent	100	25	72	62	10	3
Vehicles from opposing lanes:						
Number	825	533	262	197	65	30
Percent	100	64	32	24	8	4

reported in tables 7 and 8. No trends are evident. Of those drivers for whom the reported physical condition was not "normal," about five out of six were asleep or fatigued. Of those drivers for whom sobriety was reported, fewer than one out of three had been drinking. In an earlier study of fatal accidents in northwestern States, it was found that drivers responsible for fatal accidents on the Interstate System were less likely to have been drinking than those on non-Interstate highways.[2]

Drinking drivers are responsible for a larger share of the multiple-vehicle than single-vehicle fatal accidents, largely because of their responsibility for head-on collisions caused by driving the wrong way. Over three-quarters of fatal wrong-way, head-on collisions appear to be caused by drivers who had been drinking.

[2] "Fatal Highway Accidents in Federal Highway Administration Region 8, April 1969—March 1970," *U.S. Department of Transportation, Federal Highway Administration,* June 1971 (unpublished).

Information as to whether drivers had or had not been drinking was reported for over three-quarters of the fatal accidents (table 9). Of those drivers involved in fatal accidents—whether considered responsible for the accident or not—21.3 percent had been drinking. The percentage was higher for drivers under 25 years old than for older drivers but the percentage for the under 25 group decreased during the 1968–71 period.

Possibly because drivers are generally more alert in the heavier traffic where accidents are likely to involve more than one vehicle, fewer than 9 percent of the drivers responsible for multiple-vehicle

Table 3.—Fatal accidents on completed sections of the Interstate System, 1968–71—total travel by vehicle types

Type of vehicle [1]	Vehicle Miles [2]: Number (millions)	Vehicle Miles [2]: Percent
Total, all types	611,539	100.0
Passenger vehicles	477,612	78.1
Property-carrying vehicles:		
Combinations	60,542	9.9
All single-unit trucks:		
Panels and pickups	48,923	8.0
Other single-units	24,462	4.0
Total single-units	73,385	12.0
Total property-carrying	133,927	21.9

[1] Includes the one vehicle primarily responsible for each accident, as indicated by police investigation reports.

[2] Based on estimates by Office of Planning, Federal Highway Administration.

Table 4.—Fatal accidents on completed sections of the Interstate System, 1968–1971—types of vehicles involved in each type of accident [1]

Type of vehicle [2]	Total accidents	Single-vehicle accidents [3]: Total	Single-vehicle: Ran off road	Single-vehicle: Pedestrian	Single-vehicle: Collision with parked vehicle	Multiple-vehicle accidents [3]: Total	Multiple-vehicle: Rear-end collisions	Head-on collisions: Total	Head-on collisions: Wrong-way	Head-on collisions: Vehicle from opposite lane	Broadside	Sideswipe
Total, all types .... number	12,387	8,213	6,404	1,063	445	4,174	1,856	1,523	626	825	300	495
Percent distribution:												
Passenger:												
Sedans	65.4	66.2	68.4	62.3	59.6	63.6	54.2	74.1	76.5	72.9	68.7	63.7
Convertibles	5.0	5.6	6.1	3.0	3.8	4.1	3.8	4.8	3.8	5.3	3.0	3.4
Station wagons	7.4	7.8	7.9	8.2	4.5	6.5	6.4	6.5	5.9	7.3	6.0	7.3
Buses—under 10 passengers	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.3	0.5	—	0.3	0.2
Buses—10 and over	0.2	0.2	0.1	0.6	0.2	0.2	0.4	—	—	—	0.7	0.2
Motorcycles	1.2	1.3	1.1	0.1	0.7	1.2	1.6	0.4	0.2	0.5	1.7	1.8
Campers	0.6	0.6	0.6	0.1	1.1	0.5	0.6	0.4	0.6	0.2	—	—
Total passenger	80.0	81.9	84.5	74.4	70.1	76.3	67.2	86.5	87.5	86.2	80.4	76.6
Property carrying:												
Combinations	9.3	7.9	7.0	9.7	16.4	12.2	19.8	3.9	0.2	6.6	8.3	11.1
Panels and pickups	7.5	7.3	6.8	7.8	8.5	8.0	8.0	7.9	11.3	5.1	7.7	8.5
Single-unit trucks	2.3	1.9	1.4	2.9	3.9	3.0	4.2	1.5	0.8	1.9	3.3	3.2
Other property [4]	0.9	1.0	0.3	5.2	1.1	0.5	0.8	0.2	0.2	0.2	0.3	0.6
Total property	20.0	18.1	15.5	25.6	29.9	23.7	32.8	13.5	12.5	13.8	19.6	23.4

[1] This table is the converse of table 5.
[2] Includes the one vehicle primarily responsible for each accident, as indicated by police investigation reports.
[3] Types of accidents that occurred less frequently (see table 1) not shown separately.
[4] Includes a few highway maintenance vehicles.

Table 5.—Fatal accidents on completed sections of the Interstate System, 1968–1971—types of accidents in which each vehicle type was involved [1]

Type of accident	Passenger vehicles [2]: Total	Sedans	Convertibles	Station wagons	Motorcycles	Property-carrying vehicles [2]: Total [4]	Combinations	Panels and Pickups	Single unit trucks
Total, all types—number	9,909	8,097	622	911	153	2,478	1,157	931	284
Percent distribution:									
Single vehicle:									
Ran off road	54.6	54.1	63.2	55.5	45.1	40.0	38.6	46.8	31.7
Overturn on road	1.1	0.7	1.0	1.2	19.0	1.5	0.4	2.3	3.9
Collision-parked vehicle	3.1	3.3	2.7	2.2	2.0	5.4	6.3	4.1	6.0
Pedestrian	8.0	8.2	5.1	9.5	0.6	11.0	8.9	8.9	10.9
Other	1.0	0.9	0.8	1.6	0.6	2.2	2.0	2.1	3.1
Total single vehicle	67.8	67.2	72.8	70.0	67.3	60.1	56.2	64.2	55.6
Multiple vehicle:									
Rear-end collision	12.6	12.4	11.3	13.1	19.6	24.5	31.8	15.9	27.1
Head-on collision:									
Wrong-way driver	5.5	5.9	3.8	4.1	0.6	3.2	0.1	7.6	1.8
Vehicle from opposite lane	7.2	7.4	7.1	6.6	2.7	4.6	4.7	4.5	5.6
Other	0.6	0.6	0.8	0.2	0.6	0.5	0.3	0.8	0.7
Total head-on collision	13.3	13.9	11.7	10.9	3.9	8.3	5.1	12.9	8.1
Broadside collision	2.5	2.6	1.5	2.0	3.3	2.4	2.2	2.5	3.5
Sideswipe	3.8	3.9	2.7	4.0	5.9	4.7	4.7	4.5	5.7
Total multiple vehicle	32.2	32.8	27.2	30.0	32.7	39.9	43.8	35.8	44.4

[1] This table is the converse of table 4.
[2] Includes the one vehicle primarily responsible for each accident, as indicated by police investigation reports.
[3] Data not shown separately for the accidents for which buses and campers were primarily responsible.
[4] Data not shown separately for the accidents for which highway maintenance and farm vehicles were primarily responsible.

Table 6.—Age and sex of drivers in fatal accidents on completed sections of the Interstate System, 1968–1971 [1]

Age	Total accidents			Single-vehicle accidents			Multiple-vehicle accidents		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Drivers, all ages [2] ....number	10,177	1,991	12,168	6,684	1,384	8,068	3,493	607	4,100
Percent distribution:									
Under 25:									
15 and under	0.3	0.2	0.3	0.4	0.3	0.4	0.2	0.2	0.2
16	1.1	0.9	1.0	1.2	0.6	1.1	0.8	1.3	0.9
17	2.0	2.1	2.0	2.3	2.2	2.3	1.5	1.6	1.5
18	3.8	3.6	3.8	4.3	3.7	4.2	2.7	3.3	2.8
19	4.0	3.3	3.9	4.5	3.8	4.4	3.2	2.3	3.0
20-24	21.3	19.1	21.0	23.3	20.9	22.9	17.4	15.2	17.1
Total under 25	32.5	29.2	32.0	36.0	31.5	35.3	25.8	23.9	25.5
25-34	23.6	22.0	23.3	23.1	22.7	23.0	24.6	20.4	24.0
35-44	17.2	17.0	17.1	16.3	16.1	16.2	18.9	19.1	18.9
45-54	13.8	14.8	14.0	12.9	14.2	13.2	15.6	16.0	15.7
55-64	7.8	10.0	8.2	7.3	9.5	7.7	8.8	11.2	9.2
65-74	3.4	5.5	3.7	2.9	4.9	3.3	4.2	7.1	4.6
75 and over	1.7	1.5	1.7	1.5	1.1	1.3	2.1	2.3	2.1

[1] Data in this table refer to the one driver responsible for each accident, as indicated by police investigation reports.
[2] Excludes 219 drivers whose age/or sex was not reported.

Table 7.—Fatal accidents on completed sections of the Interstate System, 1968–1971—condition of drivers, as reported by investigators [1]

Driver condition	Total accidents	Single-vehicle accidents			Multiple-vehicle accidents	
		Total	Ran off road	Collision with parked vehicle	Total	Rear-end
Total drivers, all conditions:						
Number	12,387	8,213	6,404	445	4,174	1,856
Percent	100	100	100	100	100	100
Conditions not reported:						
Number	3,466	2,253	1,981	117	1,213	489
Percent	28	27	31	26	29	26
Condition reported:						
Number	8,921	5,960	4,423	328	2,961	1,367
Percent	100	100	100	100	100	100
Normal:						
Number	6,567	4,064	2,684	205	2,503	1,073
Percent	74	68	61	63	85	78
Total defects reported:						
Number	2,354	1,896	1,739	123	458	294
Percent	100	100	100	100	100	100
Asleep:						
Number	1,774	1,502	1,384	101	272	198
Percent	75.4	79.2	79.6	82.1	59.4	67.4
Fatigued:						
Number	191	112	95	12	79	51
Percent	8.1	5.9	5.5	9.8	17.2	17.4
Ill:						
Number	188	147	140	5	41	16
Percent	8.0	7.7	8.0	4.1	8.9	5.4
Physical Handicap:						
Number	69	39	33	2	30	10
Percent	2.9	2.1	1.9	1.6	6.6	3.4
Distracted:						
Number	119	89	82	3	30	18
Percent	5.1	4.7	4.7	2.4	6.6	6.1
Other:						
Number	13	7	5	—	6	1
Percent	0.5	0.4	0.3	—	1.3	0.3

[1] Data in this table refer to the one driver primarily responsible for each accident, as indicated by police investigation reports.

Table 8.—Fatal accidents on completed sections of the Interstate System, 1968–1971—sobriety of drivers, as reported by investigators [1]

Driver sobriety [2]	All accidents	Single-vehicle accidents: Total	Single-vehicle accidents: Ran off road	Single-vehicle accidents: Collision with parked vehicle	Multiple-vehicle accidents: Total	Head-on collisions: Total	Head-on collisions: Wrong-way drivers	Rear-end collisions	Sideswipe
Total drivers, all conditions:									
Number	12,387	8,213	6,404	445	4,174	1,523	626	1,856	495
Percent	100	100	100	100	100	100	100	100	100
Sobriety not reported:									
Number	3,543	2,416	2,136	126	1,127	464	197	473	123
Percent	29	29	33	28	27	30	31	25	25
Sobriety reported:									
Number	8,844	5,797	4,268	319	3,047	1,059	429	1,383	372
Percent	100	100	100	100	100	100	100	100	100
Not drinking:									
Number	6,003	4,048	2,766	198	1,955	555	93	964	252
Percent	67.9	69.8	64.8	62.1	64.2	52.4	21.7	69.7	67.8
Had been drinking:									
Number	2,841	1,749	1,502	121	1,092	504	336	419	120
Percent	32.1	30.2	35.2	37.9	35.8	47.6	78.3	30.3	32.2
Intoxicated:									
Number	915	525	447	42	390	195	149	133	44
Percent	10.3	9.1	10.5	13.2	12.8	18.4	34.7	9.6	11.8
Impaired:									
Number	315	183	142	17	132	54	40	54	18
Percent	3.6	3.2	3.3	5.3	4.3	5.1	9.3	3.9	4.8
Not impaired:									
Number	114	89	64	4	25	5	1	16	3
Percent	1.3	1.5	1.5	1.3	0.8	0.5	0.2	1.2	0.8
Extent of impairment not reported:									
Number	1,446	918	819	55	528	245	144	205	54
Percent	16.3	15.8	19.2	17.2	17.3	23.1	33.6	14.8	14.5
Under influence of drugs:									
Number	51	34	30	3	17	5	2	11	1
Percent	0.6	0.6	0.7	0.9	0.6	0.5	0.5	0.8	0.3

[1] Data in this table refer to the one driver responsible for each accident, as indicated by police investigation reports.
[2] As reported by police investigators.

Table 9.—Fatal accidents on completed sections of the Interstate System, 1968–1971—age and sobriety of drivers, as reported by investigators [1]

Age	Total number of drivers	Drivers not reported: Number	Drivers not reported: Percent of all drivers	Total number reported	Reported as drinking: Number	Reported as drinking: Percent of all drivers	Reported as drinking: Percent of reported
Number of drivers, all ages [2]	17,611	3,765	21.4	13,846	2,946	16.7	21.3
Under 25:							
17 and under	599	107	17.9	492	165	27.5	33.5
18	568	133	23.4	435	98	17.3	22.5
19	584	150	25.7	434	110	18.8	25.3
20-24	3,359	815	24.3	2,544	684	20.4	26.9
Total under 25	5,010	1,205	24.1	3,805	957	19.1	25.2
25-34	4,239	837	19.7	3,402	809	19.1	23.8
35-44	3,279	634	19.3	2,645	570	17.4	21.6
45-54	2,686	571	21.3	2,115	388	14.4	18.3
55-64	1,533	334	21.8	1,199	158	10.3	13.2
65-74	626	135	21.6	491	47	7.5	9.6
75 and over	238	49	20.6	189	17	7.1	9.0

[1] This table includes drivers of all vehicles involved in the accidents as opposed to table 8, which includes only one driver for each accident.
[2] Excludes 314 drivers whose ages were not reported.

fatal accidents were reported as "asleep" or "fatigued"; for single-vehicle fatal accidents, almost 20 percent of the drivers responsible were reported to be asleep or fatigued.

Common Types of Fatal Accidents on the Interstate System

Single-vehicle, ran-off-road accidents

More than half of the fatal motor vehicle traffic accidents on Interstate highways are single-vehicle, ran-off-road accidents (table 1). In almost all fatal accidents of this type, the vehicle strikes a fixed object or overturns, or does both (table 10).

In more than four out of five fatal Interstate single-vehicle, ran-off-road accidents a fixed object is struck by the vehicle. Fixed objects, in this context, include both the more obvious objects such as signs, trees, bridges and guardrail, and objects which are less likely to be thought of as "fixed objects," such as curbs, ditches and embankments. Judgment clearly plays a large part in deciding whether or not a moderately sloping embankment is to be classified as a fixed object.

In fixed-object accidents, guardrail is the most common target. Guardrails or dividers are reported as the first object struck in 36 percent of fixed-object accidents (table 11) and as the second object struck in 6 percent of these accidents (table 12). When a second object is hit following a collision with a guardrail or divider, it is usually a bridge or overpass structure. Bridges or overpasses are also commonly the first object struck, this occurring in about 18 percent of fixed-object accidents.

Overturning has become more common in single-vehicle accidents. From 1968 to 1971, the percentage of ran-off-road accidents in which the vehicle overturns—sometimes after striking a fixed object—has risen from less than 50 percent to over 60 percent. As a percentage of all fatal motor-vehicle accidents, overturns have risen from 26 percent to 31 percent. The reason for the change is not clear. It might be due to higher speeds or to changes in vehicle design. It could be an indirect result of the current program to remove fixed objects, or to reduce the hazard of striking them. Where formerly a vehicle might have struck a massive sign support and come to a stop, it might now hit a breakaway sign and go on to overturn. It should be noted that single-vehicle, ran-off-road accidents have decreased each year relative to other accidents—going down from 53.1 to 50.5 percent of all fatal Interstate traffic accidents from 1968 through 1971. Thus the increase in overturns has been more than balanced by a decrease in other types of single-vehicle accidents.

Overturning occurs in a greater proportion of rural than urban ran-off-road accidents (*2*). About two-thirds of the vehicles involved in single-vehicle, ran-off-road fatal accidents on rural sections of the Interstate System overturn, while on urban sections fewer than half overturn.

About 83 percent of ran-off-road accidents—a slightly higher percentage than for all fatal Interstate accidents combined—occurred while the pavement was dry. Ran-off-road fatal accidents do not typically occur at night more than other fatal accidents. Ran-off-road accidents are often associated with curves; about 29 percent of this type of accident were reported as having taken place on curved sections of road, whereas only about 13 percent of all other types of fatal accidents combined were on curves.

Almost a quarter of the drivers in single-vehicle, ran-off-road accidents were asleep or fatigued, even though 46 percent of these accidents occurred during daylight hours. Of the drivers considered responsible for other types of fatal Interstate accidents less than one-tenth were reported to have been asleep or fatigued. In addition, for the drivers considered responsible for ran-off-road accidents, the proportion who had been drinking was above average for Interstate fatal accidents.

About 60 percent of the accidents for which drivers under age 25 were responsible were single-vehicle, ran-off-road accidents; less than half of the fatal accidents caused by older drivers were of this type.

Passenger vehicles are more likely than property-carrying vehicles to be involved in ran-off-road fatal accidents—55 percent of the passenger vehicles and 40 percent of the property-carrying vehicles operated by drivers considered responsible for fatal accidents were in ran-off-road accidents (table 5).

It is fortunate that the most common type of fatal accident on the Interstate System—the single-vehicle, ran-off-road accident—is among the least costly in terms of deaths, injuries, and property damage per fatal accident.

Rear-end collisions

Approximately 15 percent of the fatal motor-vehicle traffic accidents on Interstate highways in the 1968–71 period were rear-end collisions. As is the case with single-vehicle ran-off-road accidents, rear-end collisions tend to take place when pavement and weather conditions are better than is normal for fatal accidents. And more than 91 percent of the rear-end collisions occurred on straight highways.

Perhaps the most distinctive characteristic of fatal rear-end collisions on Interstate highways is the disproportionate number of those accidents for which the

Table 10.—Characteristics of single-vehicle, off-the-road fatal accidents on completed sections of the Interstate System, 1968–1971

Type of accident	Total		Vehicles leaving the road			
			Left side of road		Right side of road	
	Number	Percent	Number	Percent	Number	Percent
Total accidents, all types	6,404	100.0	3,090	100.0	3,314	100.0
Struck fixed object:						
Total	5,199	81.2	2,310	74.8	2,889	87.2
Overturned	2,454	38.3	1,120	36.2	1,334	40.3
Overturned only	1,179	18.4	769	24.9	410	12.4
All overturns	3,633	56.7	1,889	61.1	1,744	52.7
Off the road only	26	0.4	11	0.3	15	0.4

Table 11.—Fixed objects struck first in single-vehicle, off-the-road fatal accidents on completed sections of the Interstate System, 1968–1971

First object struck	Number	Percent
Total, all objects	5,199	100.0
Guardrail [1]	1,468	28.3
Bridge or overpass	918	17.7
Sign	370	7.1
Embankment	511	9.8
Curb	321	6.2
Divider [2]	391	7.5
Pole [3]	220	4.2
Ditch or drain	313	6.0
Culvert	156	3.0
Fence [4]	106	2.0
Tree	107	2.1
Rocks	64	1.2
Other	254	4.9

[1] Includes cable type.
[2] Includes rail, concrete, and chainlink.
[3] Principally light poles.
[4] Principally right-of-way fences.

drivers of large trucks are considered responsible. The drivers of tractor-trailer combinations appear to be responsible for about 20 percent of fatal rear-end collisions but for only 6 percent of other fatal multiple-vehicle accidents on Interstate highways.

Drivers are reported as "asleep" or "fatigued" more often in rear-end collisions than in the other types of multiple-vehicle collisions but considerably less often than in single-vehicle, ran-off-road accidents. The proportion of drivers responsible for fatal rear-end collisions who were reported to have been drinking was below that for other Interstate fatal accidents during the 4-year period.

Property damage per fatal accident is higher for rear-end collisions than for any other accident type, primarily because of the disproportionate involvement of large trucks.

Head-on collisions

For the 1968–71 period, about 12 percent of fatal motor-vehicle traffic accidents on Interstate highways were head-on collisions. There was some increase from year to year during the 4-year period.

Quite different characteristics have been observed for two types of fatal head-on collisions—wrong-way, head-on collisions involving a vehicle traveling in the wrong direction on a roadway under the control of its driver and cross-median, head-on collisions which occur when drivers in the proper lanes lose control and cross into opposing traffic.

While fatal cross-median, head-on collisions constitute less than 7 percent of all fatal Interstate accidents, they include about 14 percent of the fatal accidents which occur on pavements which are wet, icy, or snowy. There is a sharp contrast between the 43 percent of cross-median, head-on and the 13 percent of wrong-way, head-on fatal collisions which occur on such wet, icy, or snowy pavements. While 44 percent of all fatal accidents on Interstate highways take place in daylight hours, about 65 percent of cross-median head-ons and only 25 percent of wrong-way, head-on collisions do so.

Head-on collisions are more severe in terms of loss of life than other types of fatal accidents. There are about 1.6 deaths per fatal head-on collision; other accident types average 1.0 to 1.2 deaths per accident (table 1).

Neither type of head-on collision appears to be causally related to highway alinement—over 80 percent of these fatal collisions take place on sections of highway reported to be straight.

Cross-median fatal accidents involve an above-average proportion of women drivers. Almost 10 percent of the fatal accidents for which female drivers were considered responsible were cross-median, head-on collisions; less than 6 percent of the fatal accidents for which male drivers were responsible were of this type.

In wrong-way, head-on collisions, a disproportionate number of older drivers

Table 12.—First and second fixed objects struck in single-vehicle, off-the-road fatal accidents on completed sections of the Interstate System, 1968–1971

First object struck	Guardrail	Bridge or overpass	Sign	Embankment	Curb	Divider	Pole	Ditch	Culvert	Fence	Tree	Rocks	Other
Second object struck:													
None	530	741	274	330	72	192	161	207	108	63	92	51	124
Bridge	355	64	24	14	52	42	13	12	8	2	3	—	22
Embankment	229	25	14	20	22	27	7	28	15	13	1	2	17
Guardrail	74	23	12	2	62	44	7	4	5	—	—	2	16
Pole	53	6	12	4	40	14	4	3	1	3	—	—	5
Sign	73	2	3	5	18	15	12	7	1	—	—	—	15
Ditch	41	29	13	35	9	13	9	3	3	7	1	4	15
Culvert	18	1	6	18	4	2	—	13	1	2	—	—	4
Curb	4	5	—	1	9	2	—	—	2	1	—	—	2
Divider	27	8	1	5	16	22	1	—	—	—	—	—	1
Fence	25	5	4	27	6	6	4	22	5	3	3	—	5
Tree	12	1	2	27	4	—	—	5	4	7	5	3	3
Other	27	8	5	23	7	12	3	9	3	5	2	2	25
Total, all collisions	1,468	918	370	511	321	391	220	313	156	106	107	64	254

were considered responsible. Drivers 65 years old or older apparently caused over 12 percent of wrong-way, head-on collisions but only about 5 percent of the total number of fatal accidents on Interstate highways in the 4-year study period.

The drivers of pickup and panel trucks are responsible for more than their share of wrong-way, head-on collisions; larger trucks are rarely involved in this type of accident.

Most notable about head-on collisions is the condition of the driver in wrong-way accidents. Almost four out of five drivers for whom this sort of information was reported had been drinking and many were obviously intoxicated (table 8); this was more than double the reports of drinking in other fatal Interstate accidents and adds considerably to the difficulty of devising countermeasures. Until the public places a greater stigma upon driving under the influence of alcohol, it will be difficult to reduce the number of wrong-way, head-on collisions.

Pedestrian accidents

From 1968 through 1971, 8.5 percent of all fatal motor-vehicle traffic accidents on Interstate highways were pedestrian accidents. This is considerably less than the 21.6 percent reported for pedestrian accidents on all highways in the United States during 1971 (*3*) but quite high when it is considered that pedestrians are not generally permitted on Interstate highways. It is also noteworthy that, as a percentage of all Interstate fatal accidents, pedestrian accidents have risen each year, going from 7.8 percent in 1968 to 9.8 percent in 1971.

About 70 percent of the deaths in Interstate pedestrian accidents involve trespassers—hitchhikers and others who have no legitimate business on the highway; the others are nontrespassers—such as persons who have left disabled vehicles.

Except for wrong-way, head-on collisions, pedestrian accidents occur at night more often than is true for other types of fatal Interstate accidents. Only about one-quarter of these accidents occurred in daylight.

Of the four major types of Interstate fatal accidents, only pedestrian accidents occur more frequently in urban than rural areas. The 1969–70 study cited above (*2*) showed that approximately 8 percent of rural and over 18 percent of urban single-vehicle fatal Interstate accidents were pedestrian accidents. Disproportionately high numbers of pedestrians were killed on unlighted sections of urban Interstate highways. Dark clothing, intoxication, and the possibility of suicide are often mentioned in police reports on fatal pedestrian accidents.

The drivers whose vehicles strike pedestrians are rarely reported to be asleep or fatigued and infrequently reported to have been drinking. For those cases in which such information was available, only about 8 percent of the drivers responsible for pedestrian fatal accidents had been drinking, whereas for all Interstate fatal accidents about 32 percent of the drivers responsible had been drinking.

In general, the statistics for pedestrian accidents on Interstate highways indicate that these accidents occur largely in hazardous situations which are created by pedestrians themselves. There were without question some suicides counted among these accidents, but it is probable that many hitchhikers and other pedestrians would not have intentionally exposed themselves to this hazard had they understood the danger of being on the pavement or shoulder of a high-speed freeway.

Search for Countermeasures

The primary reason for the study of Interstate fatal accidents is that better understanding will aid in the search for countermeasures designed to avoid future accidents. Prospective countermeasures include modification of human behavior, changes in the design and maintenance of motor vehicles, and alteration of the highway and other elements of the highway environment.

Countermeasures designed to alter human behavior need broad public support when personal freedom will be restricted. That this support is difficult to obtain is evident from the general reluctance to establish and enforce strong regulations pertaining to the control of hitchhiking and to the operation of motor vehicles while under the influence of alcohol. Yet changes in vehicles and in the environment will not provide complete protection for and from drivers who are asleep or intoxicated. Both wrong-way, head-on collisions and pedestrian accidents might be reduced by strengthening enforcement policies. Wrong-way, head-on collisions might also be reduced by more subtle and less coercive measures—by continuing to improve highway signs and lighting, for example.

The introduction of safety belts is an example of a vehicle modification designed to reduce death and injury in motor vehicle accidents. This type of modification might reduce deaths in ran-off-road, rear-end and head-on accidents, but does little to protect pedestrians.

Highway improvements being made under current programs to reduce the risk of highway death or injury include installation of breakaway signs, removal of fixed objects, improvement of guardrail, installation of median barriers and other types of improvement. In general, these improvements will reduce the number of severity of ran-off-road accidents and cross-median, head-on collisions. They will probably have less effect on pedestrian, rear-end, and wrong-way, head-on accidents.

It is expected that the study of accidents will lead to accelerated development of effective countermeasures and help to reduce death and injury in motor-vehicle accidents.

REFERENCES

(*1*) "Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems/1970," *U.S. Department of Transportation, Federal Highway Administration.*

(*2*) Harold R. Hosea and Benjamin V. Chatfield, "Characteristics of Rural and Urban Fatal Accidents on the Interstate Highway System, 1969-70," *Public Roads,* vol. 37, No. 1, June 1972.

(*3*) "Accident Facts, 1972 Edition," *National Safety Council,* p. 46.

Time-Lapse Television: A Highway Engineering Tool

OFFICE OF TRAFFIC OPERATIONS

Reported by WILLIAM T. BAKER, JAMES C. WILLIAMS,[1] and CHARLES W. DALE, Highway Engineers, Traffic Performance and Analysis Division

Introduction

THE continuing research of highway problems is highly dependent on traffic operations data. Unfortunately, many of the techniques used for data collection and evaluation do not fully satisfy the information requirements of today's highway control systems.

One of the most promising new tools for improving data collection, reduction and evaluation is closed-circuit television (CCTV).

Closed-circuit television may be distinguished from commercial broadcast television in that video is transmitted through coaxial cables rather than being broadcast from a transmitting tower. CCTV has been used by highway engineers in the following ways:

- *Real-time observation,* as in the surveillance of tunnels, freeways, and other places where it is desirable to respond immediately to emergency situations. For such uses, the minimum equipment necessary is the camera, coaxial cable, monitor, and power source.
- *Recording for playback,* as in the monitoring of impact attenuation devices for later detailed study. An additional component, the video tape recorder, is required for this use.

This article concerns the use of CCTV in recording for playback. For the highway engineer, video tape recording has much potential because of its relatively low cost and simplicity of operation. There has been, however, some disadvantage to this method for monitoring traffic operations because it takes as long to view a video tape as it does to record the data. Therefore, to make this kind of surveillance even more useful to highway engineers, viewing time should be reduced.

Time-lapse video for data collection and evaluation appears to be one solution to this problem. In time-lapse video recording, the tape speed is reduced, resulting in fewer recorded pictures. When the tape is viewed at the normal playback speed, the action is faster. The slower tape recording speed also permits longer periods of coverage with each reel of tape. For example, at a speed of 1:1, a 2,400-foot reel of video tape will last 1 hour; at 2:1, the reel will last 2 hours; etc.

To evaluate the use of time-lapse television for highway engineering, a study was conducted by the Office of Traffic Operations of the Federal Highway Administration. The objectives of this study were (1) to find off-the-shelf time-lapse video recording equipment which could be used for data collection, (2) to determine what information could be obtained from the time-lapse video tape, and (3) to test the use of the equipment at various highway locations. It was not the intention of this study to provide comprehensive analyses of operational traffic characteristics.

[1] Mr. James C. Williams now is with the California Division Office, Federal Highway Administration.

Procedure

Traffic operations at gores, acceleration and deceleration lanes, weaving sections, mainline splits and other conflict areas were recorded in time-lapse to see if operational difficulties could be detected. When viewed at the normal playback speed it was readily apparent that the resultant fast action on the television monitor made it easier to spot sudden stops, lane changing, and other erratic maneuvers.

A recently completed ramp modification at the junction of two Interstate routes was taped for 5 hours at a recording speed of 5:1 both before and after improvements were made (a 5:1 ratio permits 5 hours of time-lapse recording to be viewed in 1 hour at normal speed) to see how the modification affected traffic operations. A total of 22 separate items of data were extracted from the tape, including traffic volumes per lane, number of weaving maneuvers, encroachments within the gore areas, vehicle classification, and pedestrian–vehicle conflicts. It was estimated that a crew of 10 men would have been required to obtain this data by conventional means in the field. Only one field man was necessary when the video equipment was used. Data reduction was accomplished by two men in the office in one 8-hour day, replaying the tape as many times as necessary to extract the desired information.

The ability to condense many hours of real-time operation into a relatively short viewing time suggested the use of time-lapse video for the surveillance of hazardous locations on low-volume roads. At these sites it is often difficult to determine accident causation because funds are not available to pay for skilled observers at these locations over long periods of time. The cost of observation could be reduced by using unattended television equipment. To test the equipment for this application, a hazardous rural intersection was monitored at a recording speed of 29:1 for an 8-hour period. At normal playback speed, maneuvers such as U-turns, backing up, and stop sign violations within the intersection were very apparent; however, a slower playback speed was necessary to count traffic volumes.

Urban intersection studies lend themselves particularly well to analysis by video tape if a satisfactory vantage point can be found. To determine usable information that could be obtained for this application, traffic operations at several urban intersections were recorded on video tape at recording speeds of 2:1, 3:1, and 5:1. When viewed on a television monitor, it was possible to determine lane volumes, turning movements, vehicle classification, and load factor. A measurement of delay proved to be more difficult to obtain with a single camera since queue lengths often extended so far in the distance that determining the number of individual cars stopped was difficult. Another camera mounted upstream in conjunction with readily available equipment that provides camera switching or split-screen capabilities might be a solution to this problem.

A tri-level interchange that was experiencing traffic operational problems was studied by four engineer-trainees using the video equipment. Examples of the problems were shown to a group of highway administrators. The presentation demonstrated that the operators of the equipment do not need extensive training and that recorded television is useful in presenting information to highway officials.

As the study progressed, the following potential uses for time-lapse video, in addition to those tested in this study, were suggested:

- Condensing construction activities (that is, at a recording ratio of 61:1, 40 hours of construction activity can be viewed in about 40 minutes).
- Evaluating the effectiveness of speed limit changes.
- Recording traffic movements through construction areas to evaluate the adequacy of construction signing.
- Continuous monitoring of impact attenuation devices.
- Recording pedestrian movements at intersections.
- Evaluating curbside parking.
- Evaluating the effectiveness of diagrammatic signs.
- Collecting traffic operational data—time headways, lateral placement—for research studies.

Equipment

In the early stages of this project it was found that only one available time-lapse video tape recorder featured more than two recording speeds. The video tape recorder used in this study was a 10-speed model which also has the provision for recording one field at a time. (In video recording, the word "field" denotes a very short length of recorded video tape and is synonomous with the word "frame" when discussing photographic film.) To complete the package, a video camera equipped with an f/1.5 zoom lens (22.5 mm.–90 mm.), was used in conjunction with a monitor.

The recording unit was designed to operate on standard 120-volt alternating current, but for most locations in this study standard power sources were not available. For these situations two 12-volt batteries were wired in parallel and used with a static inverter. Powered by batteries, the system can be operated continuously for 8 to 24 hours, depending upon the power requirements of the inverter and the ampere-hour rating of the batteries.

Results

With the limited amount of work done to date with time-lapse video, it is difficult to determine all of the possible applications for this equipment. Major advantages of using this tool are compressed viewing time and increased reliability of data. Other advantages include the provision of a permanent tape record and an opportunity for engineers in the office to view actual traffic operations.

Time-lapse video is particularly adaptable to the surveillance of intersections, interchanges, and other special highway locations. For example, at a recording speed of 5:1, events covering a 10-hour period can be viewed in the office in 2 hours at the normal playback speed. If nothing of interest is found, the recording tape can be erased and used again.

At sites with higher traffic volumes it was necessary to use the faster recording speeds (i.e., 3:1 and 5:1) so that when the tape was viewed at the normal playback speed, vehicle motion was slow enough for a viewer to make vehicle counts and extract other data. For very light traffic volumes, operational difficulties could be detected at a recording speed of 29:1.

The selection of the proper vantage point from which traffic is to be viewed is important. It was learned early that it is desirable to mount the camera somewhat above and directly in line with the approaching traffic in order to pick up lane changing and erratic maneuvers. Volume counts were also easier to obtain when the approach was viewed at other than right angles.

It was found that lane volumes, weaving maneuvers, classification counts, turning movements, load factors for signalized intersections, and erratic maneuvers could be counted in the time-lapse mode and that for the locations in this study this data could be extracted for analysis in approximately one-half the time required by conventional methods. In most cases, one man can set up the equipment. Data reduction can be accomplished by one or two men in the office reviewing the tape as many times as is necessary to obtain the desired information.

A recording speed of 5:1 is probably the most useful for traffic operational studies. When the tape is then played back at normal speed it is possible to record most of the information that is usually obtained from field studies using manual methods.

For several days of continuous surveillance, an unmanned installation would be advantageous. This would require a weather-tight and vandal-proof housing for the equipment.

In addition to the basic equipment used in this study, there is more sophisticated components available for special situations such as video recording at night, split-screening, multi-camera switching, and remote sensing.

For a tool such as time-lapse television to be used in the field, it must be highly portable and simple to operate. The equipment used in this study was, at times, somewhat cumbersome; especially when the camera and tripod, recorder, TV monitor, inverter, and two truck batteries had to be unloaded under heavy traffic condtions. A number of manufac-

turers now market lightweight two-speed recorders; however, all but one are designed for alternating current only, necessitating the use of inverters for conversion to direct current.

Conclusions

The use of time-lapse video recording equipment appears to be suitable for data collection and analysis in the highway engineering field. The time savings in data collection and reduction along with the increased reliability of the data would seem to justify the initial investment in equipment.

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research and Development. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R Research)—Performing State Highway Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Highway Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operations for Safety

FCP Project 1A: Traffic Engineering Improvements for Safety.

Title: Psychophysiologic Evaluation of the Effectiveness of Devices for Preventing Lane Drift and Run-off-the-Road Accidents. (FCP No. 41A2752)

Objective: Study is designed to supplement California's existing programs for evaluating raised lane dividers and run-off-the-road accident prevention devices.

Performing Organization: Human Factors Research, Goleta, Calif. 93017

Expected Completion Date: June 1973.

Estimated Cost: $67,000 (HP&R)

FCP Project 1C: Analysis and Remedies of Freeway Traffic Disturbances.

Title: Evaluation of Estimates of Traffic Parameter from Presence Detector Data. (FCP No. 41C1502)

Objective: This study will evaluate the effect of detector spacing and averaging time on (1) the estimation of travel time, (2) the estimation of true occupancy, and (3) the speed of detection of incidents.

Performing Organization: University Southern California, Los Angeles, Calif. 90007

Expected Completion Date: May 1973.

Estimated Cost: $30,000 (HP&R)

Title: Aerial Film Data Reduction Methodology. (FCP No. 31C3012)

Objective: Improve the methodology used in the aerial film traffic data reduction program developed at UCLA and test its accuracy. Perform an error analysis on the more fully automated system for reducing traffic data developed at TSC.

Performing Organization: Trans Systems Center, Cambridge, Mass. 02142

Expected Completion Date: June 1973.

Estimated Cost: $50,000 (FHWA Administrative Contract)

Title: Prediction of Freeway Disturbance Effects. (FCP No. 31C3042)

Objective: To develop an analytic description of freeway shock formation, propagation and dissipation in order to determine efficient indicators of congested flow and disturbances on freeways.

Performing Organization: Trans Systems Center, Cambridge, Mass. 02142

Expected Completion Date: June 1973.

Estimated Cost: $50,000 (FHWA Administrative Contract)

FCP Project 1D: Improved Traffic Safety and Capacity on Two-Lane Rural Roads Through Speed and Hazard-Warning Displays.

Title: Development of New Passing Zone Criteria. (FCP No. 21D3552)

Objective: This staff study relates to current operational problems on two-lane rural highways concurrently with the research at the Maine Facility. A large amount of research has been performed on passing zone criteria. This effort will put this work into an implementable form through the medium of proposing new criteria and thus improve operations and safety.

Performing Organization: Federal Highway Administration, Washington, D.C. 20590

Expected Completion Date: June 1973.

Estimated Cost: $15,000 (FHWA Staff Research)

FCP Project 1F: Energy Absorbing and Frangible Structures.

Title: Basic Agreement, Task Order No. 1: "Test and Evaluation of Impact Attenuation Devices and Traffic Railings." (FCP No. 31F1134)

Objective: To perform necessary laboratory tests and design analyses and conduct fullscale vehicle crash tests in order to improve the performance of first generation impact attenuation devices and traffic railing systems, develop additional acceptable prototype devices and systems utilizing selected promising concepts, and test and evaluate other protective systems to be selected by the FHWA.

Performing Organization: Texas Transportation Institute, College Station, Tex. 77843

Expected Completion Date: May 1974.

Estimated Cost: $80,000—(FHWA Administrative Contract)

FCP Project 1J: Improved Geometric Design.

Title: Influence of Combined Highway Grade and Horizontal Alignment on Skidding. (FCP No. 51J1052)

Objective: Development of analytical procedures to determine impending loss of vehicle control due to skidding on adverse highway grades and horizontal alignment. This procedure will be developed from investigation of accident path and field observation and will highlight possible remedial action.

Performing Organization: Highway Safety Research Institute, Ann Arbor, Mich. 48105

Expected Completion Date: December 1973.

Estimated Cost: $70,000—(NCHRP) [2]

FCP Project 1K: Accident Research and Factors for Economic Analysis.

Title: Developing Accident Rates for Homogeneous Intersection Locations on North Carolina Rural Primary Highways. (FCP No. 41K1082)

Objective: This study will determine intersection, accident rate norms for rural intersections on primary highways. Data from this study will aid in planning effective and economical safety improvements at rural intersections.

Performing Organization: North Carolina State University, Raleigh, N.C. 27607

Expected Completion Date: May 1973.

Estimated Cost: $21,000—(HP&R)

FCP Category 2—Reduction of Traffic Congestion and Improved Operational Efficiency

FCP Project 2B: Development and Testing of Advanced Control Strategies in the Urban Traffic Control System.

Title: Traffic Signal Warrant for Heavy Traffic Volumes Occurring during Short Periods of Time (TAWTOP) (FCP No. 42B2273)

Objective: To establish a warrant or series of warrants with which to objectively determine the need for a traffic signal installation which would be limited to Part-time use during short time periods of heavy traffic demand.

Performing Organization: Wilbur Smith and Associates, New Haven, Conn. 06320

Expected Completion Date: May 1973.

Estimated Cost: $30,000—(HP&R)

Title: Network Flow Simulation for Urban Traffic Control System (Phase II) (FCP No. 32B3052)

Objective: Refinement and expansion of the applicability of the traffic network simulation model UTCS–1, and its use in support of the development of advanced traffic signal control systems.

Performing Organization: Peat, Marwick, Mitchell; Washington, D.C. 20590

Expected Completion Date: May 1973

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

FCP Project 2F: Dual Mode Transportation Systems.

Title: An Investigation of Highway Automation. (FCP No. 42F1021)

Objective: Further develop methods for increasing highway capacity and safety through highway automation. This contract is a one year follow-on of contract EES–276 whose cost was $962,000.

Performing Organization: Ohio State University, Columbus, Ohio. 43210

Expected Completion Date: June 1973.

Estimated Cost: $180,000 (HP&R)

FCP Project 2G: Coordination of the Traffic Operation of an Urban (Dallas) Freeway with Parallel and Cross Arterial Streets.

Title: Urban Traffic Corridor Study. (FCP No. 32G2014)

Objective: Complete the development of a traffic simulation technique to evaluate urban freeway corridor control strategies. Evaluate strategies generated for the North Central Expressway Corridor in Dallas, Texas.

Performing Organization: Trans Systems Center, Cambridge, Mass. 02142

Expected Completion Date: June 1973.

Estimated Cost: $60,000 (FHWA Administrative Contract)

FCP Category 3—Environmental Considerations in Highway Design, Location, Construction and Operation

FCP Project 3B: Quantification of Personal Preferences.

Title: Criteria for Environmental Inventories. (FCP No. 43B2072)

Objective: The proposed project intends to establish departmental procedure and approach to evaluate quickly, analyze and document changes and effects to the social, economic, and environmental variables of any given project area.

Performing Organization: Johnson, Johnson & Roy, Inc., Ann Arbor, Mich. 48104

Expected Completion Date: June 1973.

Estimated Cost: $55,000 (HP&R)

FCP Project 3F: Pollution Reduction and Visual Enhancement.

Title: Ecological Effects of Highway Construction upon Michigan Woodlots and Wetlands. (FCP No. 43F2402)

Objective: Evaluation of possible ecological effects of highway wetlands and woodlands, in order to formulate design considerations to be followed in determining the location of a highway.

Performing Organization: Michigan State University, Lansing, Mich. 48901

Expected Completion Date: June 1976.

Estimated cost: $134,000 (HP&R)

FCP Category 4—Improved Materials Utilization and Durability.

FCP Project 4B: Eliminate Premature Deterioration of Portland Cement Concrete.

Title: Internally Sealed Concrete. (FCP No. 34B1202)

Objective: To define the utility of internally sealing concrete by a process in which polymer beads are incorporated into the concrete at the time of mixing and then melted by mild heating of the cured concrete.

Performing Organization: Monsanto Research Corporation, Dayton, Ohio 45407

Expected Completion Date: November 1974.

Estimated Cost: $152,000 (FHWA Administrative Contract)

Title: Maintaining and Resurfacing Deteriorated Concrete Bridge Decks with Bonded Concrete Overlays in South Dakota. (FCP No. 44B2074)

Objective: The aim of the project is to present a system related to resurfacing and restoration of deteriorated concrete bridge decks in South Dakota, pertinent to protective covering and durability of the concrete deck.

Performing Organization: South Dakota School of Mines, Rapid City, S. Dak. 57701

Expected Completion Date: June 1975.

Estimated Cost: $50,000 (HP&R)

Title: Use of Chinle Clay and Moderate Heats for Production of Synthetic Aggregates. (FCP No. 44B2091)

Objective: Develop new manufacturing methods or modification of existing methods for producing synthetic aggregates from montmorillonite clay or clay shales without requiring excessive temperatures for transformation.

Performing Organization: Highway Research Institute, Tempe, Ariz. 85282

Expected Completion Date: August 1973.

Estimated Cost: $40,000 (HP&R)

FCP Project 4E: Techniques to Determine Critical Terrain and Environmental Features by Remote Sensing.

Title: Multiband Aerial Remote Sensing for Material Identification. (FCP No. 44E1114)

Objective: Determination of the utility of multiband aerial remote sensing for materials identification in California.

Performing Organization: Division of Highways, Sacramento, Calif. 95807

Expected Completion Date: June 1974

Estimated Cost: $19,000 (HP&R)

Title: Early Detection and Correction of Sinkhole Problecs. (FCP No. 44E2102)

Objective: Inventory areas which have active sinkholes or which are susceptible to sinkhole development; evaluate remote sensing for the location of potential sinkholes; establish guidelines to define potential sinkhole problems along existing roads or in proposed highway corridors.

Performing Organization: U.S. Geological Survey, University of Alabama 35486

Expected Completion Date: March 1975.

Estimated Cost: $45,000 (HP&R)

Category 5—Improved Design to Reduce Costs, Extend Life Expectancy and Insure Structural Safety

FCP Project 5A: Improved Protection Against Natural Hazards of Earthquake and Wind.

Title: Testing of Signs and Their Support Against Wind Forces and Vibrations. (FCP No. 45A1052)

Objective: Determine the aerodynamic force excitation, and structural stresses, frequencies and amplitudes of response of single posted signs and associated structural attachments and supports. Investigate the stress damage and fatigue life of such structures and recommend an optimum design criteria.

Performing Organization: Youngstown State University, Youngstown, Ohio 44503

Expected Completion Date: July 1974.

Estimated Cost: $50,000 (HP&R)

Title: Dynamic Response of Bridges to Seismically Induced Ground Vibrations. (FCP No. 45A2042)

Objective: To install, monitor, and service strong motion accelerographs installed on bridge structures. Measure and analyze ground motion and bridge responses in an event of an earthquake.

Performing Organization: California Division of Highways, Sacramento, Calif. 95807

Expected Completion Date: June 1974.

Estimated Cost: $36,000 (HP&R)

FCP Project 5C: New Methodology for Flexible Pavement Design.

Title: Determination of Flexible Pavement Rutting Behavior. (FCP No. 45C3111)

Objective: (1) Develop or adapt appropriate instrumentation to determine where and to what extent rutting takes place within a pavement system, (2) Formulate the mechanistic behavior of bituminous concretes by laboratory investigation, and (3) Correlate laboratory data with actual field measurements.

Performing Organization: Department of Highways, Frankfort, Ky. 40601

Expected Completion Date: June 1982

Estimated Cost: $151,000 (HP&R)

FCP Project 5F: New Techniques for Structural Inspection of Existing Bridges.

Title: Detection and Repair of Fatigue Cracking in Highway Bridges. (FCP No. 55F1022)

Objective: To compile and review methods of crack detection, to compile a list of typical fatigue susceptible welded details, and to try several life improvement methods on laboratory beam specimens, and to recommend methods for arresting the progress of fatigue damage in welded highway bridges.

Performing Organization: Lehigh University, Bethlehem, Penn. 18015

Expected Completion Date: October 1974

Estimated Cost: $100,000 (NCHRP)

Title: Subcritical Crack Growth in Steel Bridge Members. (FCP No. 55F2012)

Objective: To develop corrosion fatigue data on bridge steels in distilled water and 3 percent sodium chloride solution under stress fluctuations such as occur in actual bridges, and to develop an analytical method for predicting the cyclic life of bridges in these environments.

Performing Organization: United States Steel Corp., Monroeville, Penn. 15146

Expected Completion Date: April 1974

Estimated Cost: $100,000 (NCHRP)

FCP Project 5G: Predicting the Service Life of Bridges.

Title: Federal Computer Service Utilization. (FCP No. 35G1012)

Objective: This is computer services support in connection with Contract FH-11-7904.

Performing Organization: Johns Hopkins University, Silver Spring, Md. 20910

Expected Completion Date: June 1973.

Estimated Cost: $3,000. (FHWA Administrative Contract)

Title: Predictions of Loadings on Highway Bridges—Phase II. (FCP No. 35G1012)

Objective: An analytical technique will be developed for predicting expected stress ranges in representative highway bridge members from which stress histograms will be prepared suitable for design guides.

Performing Organization: Integrated Systems, Inc., Chevy Chase, Md. 20015

Expected Completion Date: June 1973.

Estimated Cost: $45,000. (FHWA Administrative Contract)

Title: An Investigation of the Behavior of a Three-Span Composite Highway Bridge—Phase II. (FCP No. 45G1162)

Objective: To determine the fatigue life of the bridge and to compare the results with the AASHO fatigue specifications. To discover whether the bridge properties are significantly altered by cumulative damage. To experimentally determine the maximum moving load capacity of the bridge.

Performing Organization: University of Missouri, Columbia, Mo. 65201

Expected Completion Date: December 1974.

Estimated Cost: $224,000 (HP&R)

Title: Investigation of Scratch Strain Gage-System for Monitoring Traffic Induced Strains. (FCP No. 45G1222)

Objective: Scratch strain gages will be evaluated as a strain monitoring system for highway bridges. The results of the scratch gages will be compared to electrical gages and the influence of prolonged exposure will be determined. Methods of gage protection and suitable gage lengths will be determined.

Performing Organization: Technology Incorporated, Dayton, Ohio 45431

Expected Completion Date: December 1973.

Estimated Cost: $60,000 (HP&R)

Title: Statistical Evaluation of AASHO Fatigue Specifications. (FCP No. 45G1232.)

Objective: To develop a statistical method for predicting or assessing the fatigue life of certain bridge structure details.

Performing Organization: North Carolina State University, Raleigh, N.C. 27607

Expected Completion Date: June 1975.

Estimated Costs: 31,000 (HP&R)

Title: Polymer-Impregnated Precast Structural Concrete Bridge Deck Panels. (FCP No. 35G3022)

Objective: To design a segmental system of polymer impregnated concrete bridge decking, and through laboratory testing and analysis evaluate the feasibility of its use for highway bridges.

Performing Organization: Bureau of Reclamation, Denver, Colo. 80225

Expected Completion Date: June 1974.

Estimated Cost: $126,000 (FHWA Administrative Contract)

Title: The Effect of Repeated Loads on Serviceability and Ultimate Strength of Continuous Bridge Girders Utilizing Tension Elements. (FCP No. 45G3664)

Objective: To devise and conduct an experimental investigation which may yield data regarding the behavior under repeated loads of two-span continuous girders using prestressed concrete tension elements for developing continuity over the interior support.

Performing Organization: North Carolina State University, Raleigh, N. C. 27607.

Expected Completion Date: June 1974.

Estimated Cost: $40,000 (HP&R)

FCP Category 6—*Efficiency in Construction and Maintenance Operations*

FCP Project 6A: Improved Management Methods, Materials and Equipment for Highway Maintenance.

Title: Improved Methods for Cleaning Joints in Concrete Bridge Decks. (FCP No. 46A4033)

Objective: Develop practical and economical equipment and procedures for removing debris from joints in concrete bridge decks and bridge approach slabs.

Performing Organization: Texas Transportation Institute, College Station, Tex. 77843

Expected Completion Date: August 1974

Estimated Cost: $40,000 (HP&R)

Title: Pavement Patching. (FCP No. 46A5044)

Objective: Evaluate new patching materials and methods. Develop guidelines for more effective maintenance patching programs.

Performing Organization: Department of Transportation, Albany, N.Y. 12226

Expected Completion Date: March 1974.

Estimated Cost: $58,000 (HP&R)

Highway Research and Development Reports Available From the National Technical Information Service

The following highway research and development reports are available from the National Technical Information Service, Sills Building, 5285 Port Royal Road, Springfield, Va. 22151. Paper copies are priced at $3 each and microfiche copies at 95 cents each. To order, send the stock number of each report desired and a check or money order to the National Technical Information Service. Prepayment is required.

Other highway research and development reports available from the National Technical Information Service will be announced in future issues.

STRUCTURES

Stock No.	
PB 209748	Test and Evaluation of Vehicle Arresting, Energy Absorbing and Impact Attenuation Systems—Appendix F.
PB 209924	Thick-Lift Flexible Paving.
PB 210044	Deflection Analysis of Flexible Pavements.
PB 210045	Sealers for Longitudinal Joints.
PB 210046	Overloads on Exposed Cement Treated Bases.
PB 210204	The Performance of the Foundation Under a High Embankment.
PB 210206	Design Data for Curved Bridges.
PB 210207	Skew and Elevated Support Effects on Curved Bridges.
PB 210211	Full-Scale Bridge Testing—An Evaluation of Bridge Design Criteria.
PB 210212	Pavement Roughness Measurement and Evaluation.
PB 210213	Condition Surveys Along Interstate Route I–70S.
PB 210311	Acceptance Criteria for Performed Transverse Joint Sealers. Research Report 7.
PB 210314	Instability of Horizontally Curved Members; Buckling of Stiffened Curved Plates.
PB 210361	Slab Behavior of a Prestressed Concrete Box-Beam Bridge, Hazleton Bridge.
PB 210732	Horizontally Curved Highway Bridges—A Fully Compatible Annular Segment Finite Element.

MATERIALS

Stock No.	
PB 210043	Study of Compounds in Dual Role of Curing Agent and Protective Treatment of Concrete.
PB 210245	Nondestructive Determination of Pavement Thickness Using Electrical Resistivity Techniques.
PB 210049	Evaluation of Raised Pavement Markers.
PB 210058	Fingerprinting of Highway Asphalts: A Method for Cataloging and Identifying Highway Asphalts.
PB 210102	Nuclear Test Equipment Investigation Asphaltic Concrete Density Gauges.
PB 210315	D-Cracking of Concrete Pavements in Ohio—(1st Interim Report)

ENVIRONMENT

PB 210047	Bridge Deck—Frosting—Valley Environment.
PB 210316	Crownvetch an Adaptable Ground Cover for Massachusetts Roadsides.
PB 210317	Flood Prediction Methods for Pennsylvania Highway Crossings.

IMPLEMENTATION

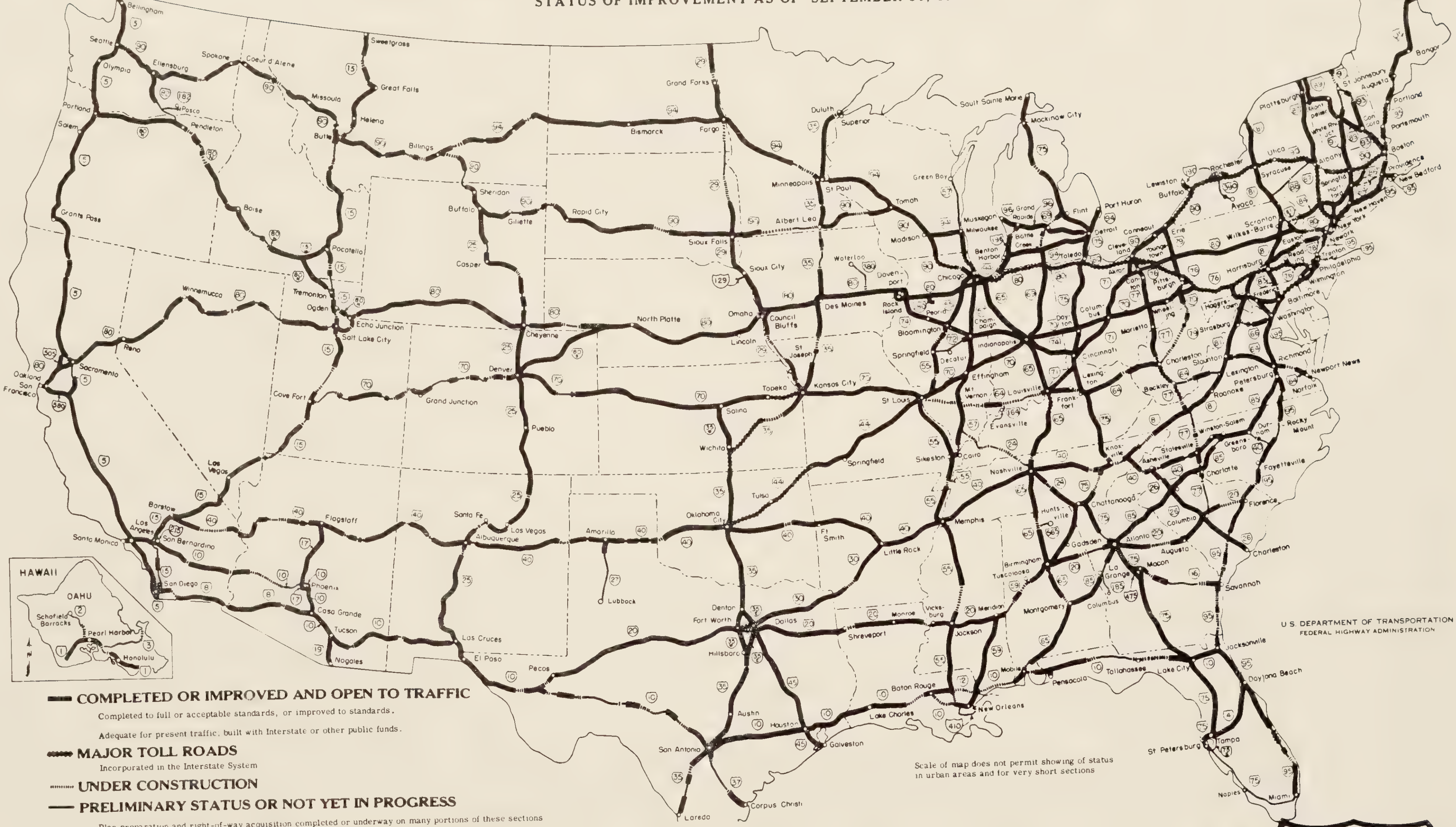
Stock No.	
PB 209423	Development of a New Low-Profile Highway Striping for Wet-Night Visibility: Phase 1, Feasibility.
PB 209619	Proceedings, Committee on Computer Technology National Conference.
PB 209740	Template Converter Program.
PB 210048	Joint Study into the Creation, Establishment and Designation of a State Scenic Highway System.
PB 210140	Pretensioned Girder Design.
PB 210178	Plot Command Language Translator Program.
PB 210205	Variable Message Fog Hazard Warning Signs to Control Vehicle Operating Characteristics.
PB 210255	A Motorist Radio Service.
PB 210269	Monetary Value Drivers Place on Comfort in Night Driving.
PB 210321	Field Test of the O.S.U./O.D.H. Ultrasonic Pavement Thickness Gage.
PB 210360	Tunnel Ventilation and Air Pollution Treatment.
PB 210568	Maintenance Cost Study (Final Report).

PLANNING

PB 201958	Estimation of User Benefits from Alternative Urban Transportation Systems.
PB 210222	A Manual for Conducting Environmental Impact Studies.
PB 209925	An Economic Corridor Study: The Economic Effects of Interstate 90 Between Bozeman and Three Forks, Montana.
PB 210050	Citizen Participation in Public Hearings in Virginia.
PB 210051	The Impact of New Urban Highways on Community Traffic.
PB 210258	An Analysis of the Costs and Benefits of I–80 in Southwestern Wyoming.
PB 210515	A Disaggregated Behavioral Model of Urban Travel Demand.

THE NATIONAL SYSTEM OF INTERSTATE AND DEFENSE HIGHWAYS

STATUS OF IMPROVEMENT AS OF SEPTEMBER 30, 1972



▬ COMPLETED OR IMPROVED AND OPEN TO TRAFFIC

Completed to full or acceptable standards, or improved to standards.

Adequate for present traffic, built with Interstate or other public funds.

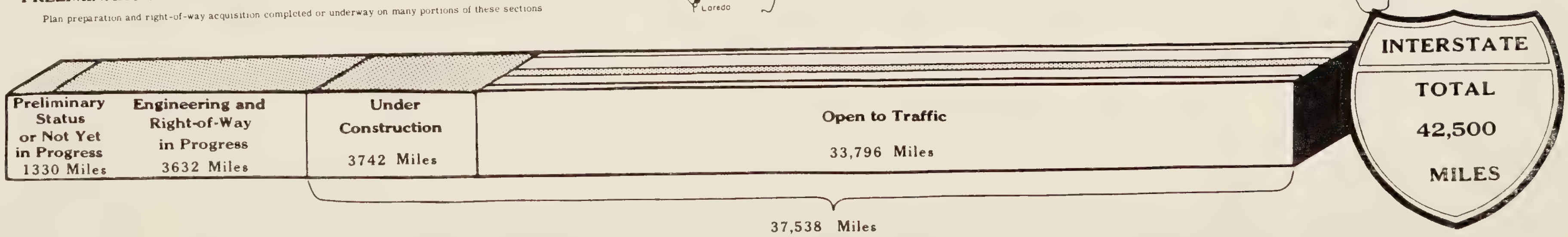
MAJOR TOLL ROADS

Incorporated in the Interstate System

UNDER CONSTRUCTION

— PRELIMINARY STATUS OR NOT YET IN PROGRESS

Plan preparation and right-of-way acquisition completed or underway on many portions of these sections



PUBLICATIONS of the Federal Highway Administration

A list of articles in past issues of PUBLIC ROADS *and title sheets for volumes 24–36 are available upon request from the Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 20590.*

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

Aggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and a new Graphical Evaluation Chart (1962). 25 cents.

America's Lifelines—Federal Aid for Highways (1969). 35 cents.

Analysis and Modeling of Relationships between Accidents and the Geometric and Traffic Characteristics of the Interstate System (1969). $1.00.

A Book About Space (1970). 70 cents.

Bicycling for Recreation and Commuting (1972). 45 cents.

Bridge Inspector's Manual (1970). $2.50.

Calibrating & Testing a Gravity Model for Any Size Urban Area (1968), $1.00.

Capacity Analysis Techniques for Design of Signalized Intersections (1967). 45 cents.

Construction Safety Requirements, Federal Highway Projects (1967). 50 cents.

Corrugated Metal Pipe (1970). 35 cents.

Emergency Application Systems for Power Brake Mechanisms of Highway Trailer Combinations (1970). $1.00.

Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems (1970). 45 cents.

Federal-Aid Highway Map (42x65 inches) (1970). $1.50.

Federal Assistance Available (1971). 10 cents.

Federal Laws, Regulations, and Other Material Relating to Highways (1970). $2.50.

The Freeway in the City (1968). $3.00.

Freeways to Urban Development (1966). 15 cents.

Guidelines for Trip Generation Analysis (1967). 65 cents.

Handbook on Highway Safety Design and Operating Practices (1968). 40 cents.
- Supplement No. 1 (Nov. 1968). 35 cents.
- Supplement No. 2 (Nov. 1969). 40 cents.

The Highway and its Environment, 3d Annual Awards Competition (1970). 60 cents.

Highway Condemnation Law and Litigation in the United States (1968):
- Vol. 1—A Survey and Critique. 70 cents.
- Vol. 2—State by State Statistical Summary of Reported Highway Condemnation Cases from 1946 through 1961. $1.75.

Highway Joint Development and Multiple Use (1970). $1.50.

Highway Research & Development Studies Using Federal-Aid Research and Planning Funds (1970). $2.50.

Highway Statistics (published annually since 1945):
- 1967, $1.75; 1968, $1.75; 1969, $1.75; 1970, $1.75.
- (Other years out of print.)

Highway Statistics, Summary to 1965 (1967). $1.25.

Highway Transportation (November 1970) 65 cents (Spring 1971), 60 cents; (Fall 1971), 45 cents; (Spring 1972), 55 cents.

Highways to Beauty (1966). 20 cents.

Hydraulic Engineering Circulars:
- No. 5—Hydraulic Charts for the Selection of Highway Culverts (1965). 55 cents.
- No. 9—Debris Control Structures (1971). 50 cents.
- No. 10—Capacity Charts for the Hydraulic Design of Highway Culverts (1965). $1.00.
- No. 11—Use of Riprap for Bank Protection (1967). 50 cents.
- No. 12—Drainage of Highway Pavements (1969). $1.00.

Hydraulic Design Series:
- No. 1—Hydraulics of Bridge Waterways, 2d ed. (1970). $1.25.
- No. 3—Design Charts for Open-Channel Flow (1961). $1.50.
- No. 4—Design of Roadside Drainage Channels (1965). 65 cents.

Hydraulic Flow Resistance Factors for Corrugated Metal Conduits (1970). 55 cents.

Identification of Rock Types (1960). 20 cents.

Interstate System Accident Research Study–1 (1970). $1.00.

Interstate System Route Log and Finder List (1971). 25 cents.

Joint Development Opportunities Outside the Highway Right-of-Way (1971). 20 cents.

Labor Compliance Manual for Direct Federal and Federal-Aid Construction, 3d ed. (1970). $3.75.

Landslide Investigations (1961). 30 cents.

License Plates (1972). 20 cents.

Manual for Highway Severance Damage Studies (1961). $1.00.

Manual of Instructions for Construction of Roads and Bridges on Federal Highway Projects (1970). $3.25 (for use with specifications—FP–69).

Manual on Uniform Traffic Control Devices for Streets and Highways (1971). $3.50.

Maximum Safe Speed for Motor Vehicles (1969). $1.00.

Modal Split—Documentation of Nine Methods for Estimating Transit Usage (1970). $1.25.

Motor Carrier Safety Regulations (1971). 65 cents.

National Highway Needs Report, H. Comm. Print 91st Cong. 70 cents.

The National System of Interstate and Defense Highways (1971). 15 cents.

The New Look in Traffic Signs and Markings. 35 cents.

Overtaking and Passing on Two-Lane Rural Highways—a Literature Review (1967). 20 cents.

Park & Recreational Facilities (1971). 45 cents.

Quality Assurance in Highway Construction. (Reprinted from PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH, vol. 35, Nos. 6–11, 1969). 50 cents.

R&D Highway and Safety Transportation Systems Studies (1971). $2.75.

Read Before Driving (1971). 15 cents.

Reinforced Concrete Bridge Members—Ultimate Design (1969). 45 cents.

Reinforced Concrete Pipe Culverts—Criteria for Structural Design and Installation (1963). 30 cents.

The Road to Your Success (1970). 70 cents.

Road-User and Personal Property Taxes on Selected Motor Vehicles (1970). 65 cents.

(Continued on reverse side)

UNITED STATES
GOVERNMENT PRINTING OFFICE
PUBLIC DOCUMENTS DEPARTMENT
WASHINGTON, D.C. 20402

OFFICIAL BUSINESS

PENALTY FOR PRIVATE USE TO AVOID
PAYMENT OF POSTAGE, $300
U.S. GOVERNMENT PRINTING OFFICE
POSTAGE AND FEES PAID

U.S.MAIL

Publications of the Federal Highway Administration—Continued

The Role of Third Structure Taxes in the Highway User Tax Family (1968). $2.25.

Safety Rest Area Development (1970). $1.00.

Second Annual Highway Beauty Awards Competition (1969). 50 cents.

Specifications for Aerial Surveys and Mapping by Photogrammetrical Methods for Highways (1968). $1.25.

Standard Alphabets for Highway Signs (1966). 30 cents.

Standard Plans for Highway Bridges:
- Vol. I—Concrete Superstructures (1968). $1.25.
- Vol. II—Structural Steel Superstructures (1968). $1.00.
- Vol. III—Timber Bridges (1969). 75 cents.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (1969). $3.50.

Study of Airspace Utilization (1968). 75 cents.

Transition Curves for Highways (1940). $2.50.

Transportation Planning Data for Urbanized Areas based on 1960 census (1970). $9.25.

Typical Plans for Retaining Walls (1969). 75 cents.

Ultrasonic Testing Inspection for Butt Welds in Highway and Railway Bridges (1968). 40 cents.