Vol. 35/No. 3 August 1968

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF PUBLIC ROADS

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

Published Bimonthly

Harry C. Secrest, *Managing Editor* ● Fran Faulkner, *Editor*
Joan H. Kinbar, *Assistant Editor*

August 1968 / Vol. 35, No. 3

U.S. DEPARTMENT OF TRANSPORTATION
ALAN S. BOYD, Secretary

FEDERAL HIGHWAY ADMINISTRATION
LOWELL K. BRIDWELL, Administrator

BUREAU OF PUBLIC ROADS
F. C. TURNER, Director

CONTENTS

COVER

Traffic backed up on Maryland highway U.S. 301 before it became a dual highway. Public Roads research is endeavoring to solve the problem of passing vehicles on 2-lane highways. See article beginning on opposite page.

THE BUREAU OF PUBLIC ROADS
FEDERAL HIGHWAY ADMINISTRATION
U.S. DEPARTMENT OF TRANSPORTATION
Washington, D.C. 20591

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. 2. 1633 Federal Building, 31 Hopkins Place, Baltimore, Md. 21201.
Delaware, District of Columbia, Maryland, Ohio, Pennsylvania, Virginia, and West Virginia.

No. 3. 1720 Peachtree Rd., N.W., Atlanta, Ga. 30309.
Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee.

No. 4. 18209 Dixie Highway, Homewood, Ill. 60430.
Illinois, Indiana, Kentucky, Michigan, and Wisconsin.

No. 5. Civic Center Station, Kansas City, Mo. 64106.
Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota.

No. 6. 819 Taylor St., Fort Worth, Tex. 76102.
Arkansas, Louisiana, Oklahoma and Texas.

No. 7. 450 Golden Gate Ave., Box 36096, San Francisco, Calif. 94102.
Arizona, California, Hawaii, and Nevada.

No. 8. 412 Mohawk Bldg., 222 SW. Morrison St., Portland, Oreg. 97204.
Alaska, Idaho, Montana, Oregon, and Washington.

No. 9. Denver Federal Center, Bldg. 40, Denver, Colo. 80225.
Colorado, New Mexico, Utah, and Wyoming.

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

No. 19. Apartado Q, San Jose, Costa Rica.
Inter-American Highway: Costa Rica, Guatemala, Nicaragua, and Panama.

Public Roads, A Journal of Highway Research, is sold by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402, at $1.50 per year (50 cents additional for foreign mailing) or 25 cents 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 Director of the Bureau of the Budget, March 16, 1966.

Vhen deciding whether to pass or not to pass on 2-lane highways, motorists in the future may be assisted by electronic systems.

Passing Aid System I Initial Experiments

BY THE OFFICE OF RESEARCH AND DEVELOPMENT BUREAU OF PUBLIC ROADS

Reported by DUKE NIEBUR, Highway Research Engineer, Economics and Requirements Division

Development of a traffic system to aid motorists in passing vehicles on 2-lane rural highways is one of the chief objectives of the Public Roads research and development program. Anyone who has driven on winding, hilly, rural roads has frequently been confronted with the problem of passing a slower vehicle ahead and has either driven many laborious miles waiting for an opportune time to pass or has ventured doubtfully into the passing maneuver on the chance that it could be accomplished without mishap. If the motorist had sufficient information about conditions on the highway ahead—whether there is an oncoming vehicle in the opposite lane and whether there is enough room on the highway to pass the car ahead and clear the oncoming vehicle—the passing maneuver not only could be executed more safely, but the volume of the traffic served by the roadway would be increased by minimizing inherent delays caused by slower vehicles.

The Public Roads research and development program has turned to electronics in the search for a method of providing information that the driver needs to pass vehicles safely on 2-lane highways. Results of experiments conducted on a 2-lane roadway with an elementary passing aid system, PAS I, are described in this article. The purpose of these experiments was to determine whether drivers would rely on information supplied electronically to indicate the absence of opposing vehicles when visual sight distance was limited. Encouraging results of the experiments, as shown by acceptance of electronically indicated passing opportunities, have prompted the planning of more advanced experiments and the development of a more sophisticated passing aid system. Work is now underway on Passing Aid System II (PAS II), which is expected to be installed on 15 miles of 2-lane rural highway during 1969.

Introduction

DRIVING on high-volume, winding, 2-lane rural highways is a problem that is known to most motorists. Restricted sight distances, oncoming traffic, and adverse environmental conditions make it difficult or impossible for a motorist to pass slow vehicles, and any one of these conditions not only encourages unsafe passing attempts but also tends to decrease average vehicle speed. Furthermore, difficult passing situations, such as those existing on winding mountain roads and in dense traffic, discourage all passing attempts and encourage the unsafe practice of tailgating.

Less known to the layman is the decrease in the capacity of a highway caused by the inability of motorists to pass vehicles ahead. Even when passing sight distances are adequate, traffic volume still may reach only 30–70 percent of the roadway's capacity (volume/capacity ratio). Unfortunately, as most 2-lane rural highways do not have unrestricted passing sight distances, the volume/capacity ratio is further reduced, and

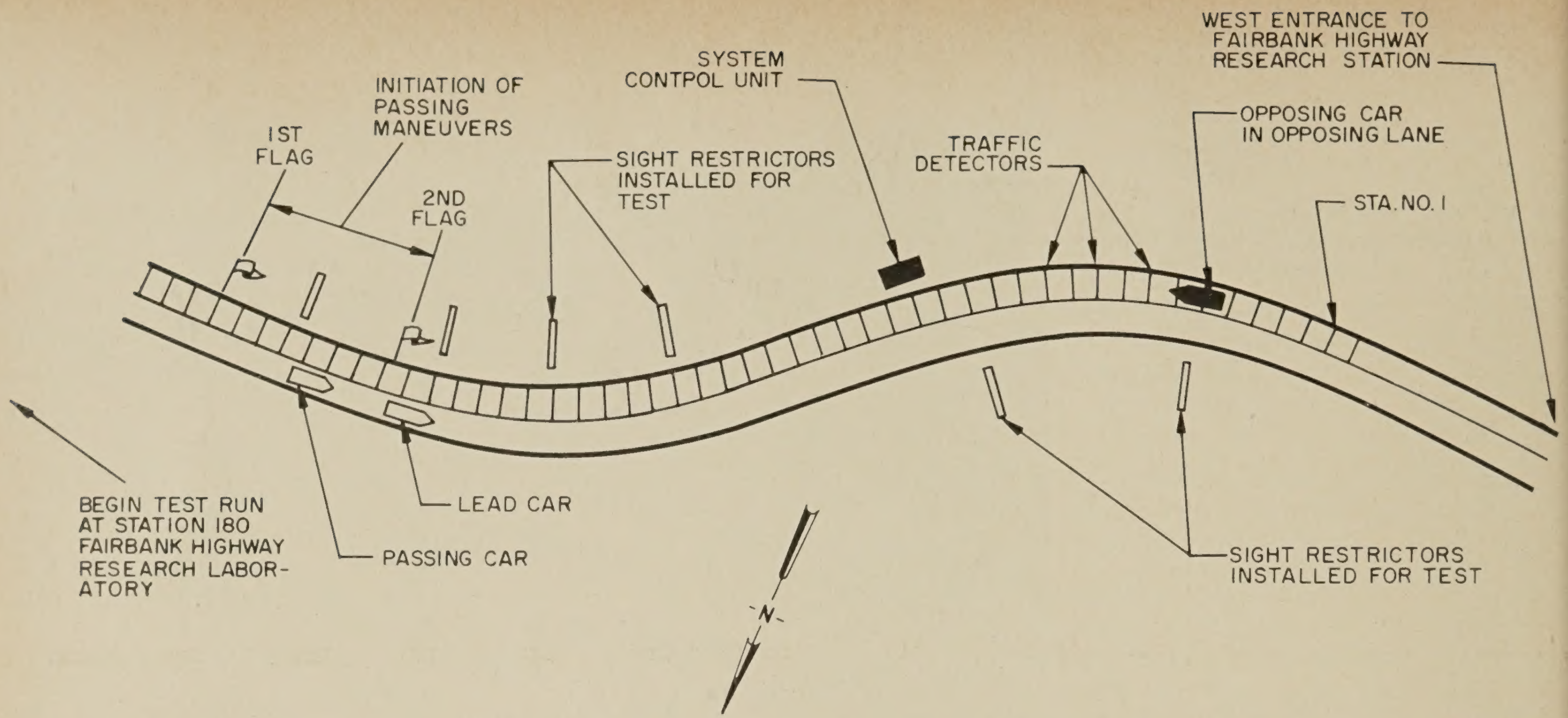

Figure 1.—Test route and operations for Passing Aid System, I.

the effect is to reduce the number of passing opportunities and create more traffic interferences—slowdowns, accidents, etc.—which reduce the service volume.

Even after the Interstate System has been completed, more vehicle-miles will be traveled on rural highways than on rural sections of the Interstate System. From this fact alone, it is evident that rural highways must be made safer. More than one-third of all accidents on these highways at present are rear-end collisions. Head-on collisions do not occur as frequently as rear-end collisions—about one-fifth of the accidents are head-on collisions—but they are likely to be more severe. Both types of accidents, however, involve the interaction of two or more drivers and their vehicles.

According to past research, a driver cannot estimate, with any degree of precision, the absolute speed of a vehicle ahead or the rate at which his own vehicle is approaching it until the two vehicles are only a few hundred feet apart. Also, according to past research, when the two vehicles are this close to each other, there is not enough time for the driver to modify his speed, especially if he is traveling at a speed typical of those on the highways today.

To avoid rear-end collisions, drivers need to be given reliable information about the speed of the vehicle ahead, or about relative speed or closure rate. Speed patterns of pairs of vehicles involved in rear-end collisions support the fact that the driver of the colliding vehicle lacked information on the vehicle ahead—more than one-third of the passenger cars were traveling at speed differences greater than 30 m.p.h. prior to collision. In normal traffic, however, less than 1 percent of pairs of cars travel at speed differences exceeding 30 m.p.h. Head-on collisions, although occurring less frequently than rear-end collisions, must be given equal attention because of their severity.

Research has shown that the average driver requires approximately 9 seconds to initiate and complete a passing maneuver on a 2-lane rural highway. Thus, if one vehicle traveling at 70 miles per hour overtakes another, a 9-second passing maneuver requires that the highway ahead be clear for a distance of more than 1,800 feet. At this distance, not only are drivers unable to estimate the relative speed of a vehicle in the opposite lane but they are incapable of determining whether that vehicle is stopped, in fact, whether its motion is toward them or away from them. Many 2-lane, bidirectional rural highway sections are without sight distances of 1,800 feet and, accordingly, are marked to prohibit passing. Moreover, the degree of precision in executing the passing maneuver has become increasingly important as traffic volumes have increased and vehicles in the opposite lane are being encountered more frequently.

Public Roads, through its national program of highway research, is endeavoring to increase travel safety on rural highways by developing methods to give the driver adequate environment information on 2-lane roadways. This information may relate to speed, acceleration, closure rate, or other information about both the vehicle ahead and the vehicle in the opposite lane.

The objective of this research is to develop a system to aid drivers solve discrimination, judgment, information, and vehicle control problems on 2-lane rural highways, and, consequently, raise highway service volumes and increase traffic safety.

Applications of electronics technology are being explored as a means to aid drivers in making judgments during overtaking and passing maneuvers. A specific application the development of an electronic aid syste that will provide the driver with informatic as to the presence, location, and speed vehicles in the opposing lane. It was post lated that over a specified distance of sufficie length, considering all combinations of vehic velocities, road grades, etc., a go or no-go ty of system could be employed.

A full-scale mockup of an electronic passi aid system has been constructed and test on the 2-lane access road to the Public Roa Fairbank Highway Research Station McLean, Va. Summarized in this article a the concepts, experimental tests, and pr cedures used to determine whether drive can and will use this electronic aid syste known as Passing Aid System I, or PAS The willingness of drivers to use PAS I, a their ability to apply it successfully as an a in passing vehicles on 2-lane highways, pr vides an indication of the advisability developing a more advanced passing system.

Considerations in Developing a Passing Aid System

To speed development of passing aid s tems, tentative decisions were made: Drivers would be given distance informat and possibly speed information or time-meeting information, and (2) the system l to be compatible with existing operations that drivers of vehicles unequipped w electronic hardware could continue to use highway.

The following basic questions need to answered before a full-scale passing system can be made available for public u

- Will drivers pass if they have informat about the absence of opposing vehi within a critical distance?

Table 1.—Test subjects used as vehicle drivers

Phase	Test subject	Age	Driving experience	Occupation	Distance driven during last 12 months		
					2-lane rural highways	Freeways	City streets
	Number	*Years*	*Years*		*Miles*	*Miles*	*Miles*
Preliminary Tests	1	20	3	Student	75	20	5, 500
	2	20	3	Student	100	1, 500	5, 500
	3	21	5	Student	500	2, 500	2, 500
	4	22	5	Student	4, 000	2, 000	2, 500
	5	23	7	BPR	500	2, 000	2, 000
	6	27	10	BPR Engineer	4, 000	7, 000	5, 000
	7	22	6	Student	100	800	2, 000
	8	30+	30	Secretary	8, 000	3, 000	1, 000
	9	24	8	Secretary	3, 000	6, 000	3, 000
	10	62	15	Secretary	500	500	1, 000
	11	23	7	BPR	500	2, 000	2, 000
Experiment 1	12	29	13	BPR Engineer	14, 000	6, 000	10, 000
	13	22	5	Secretary	5, 000	10, 000	5, 000
	14	21	1	Student	2, 500	5, 000	2, 500
	15	20	3	Student	1, 000	2, 000	2, 000
	16	58	40	BPR Foreigner	800	1, 700	3, 000
	17	-------	-------	BPR Engineer	-------	-------	-------
Experiment 2	18	35	19	BPR Engineer	4, 000	4, 000	4, 000
	19	31	10	BPR Engineer	3, 000	1, 000	6, 000
	20	45	18	BPR Engineer	4, 000	8, 000	1, 000
	21	26	11	BPR Engineer	8, 000	8, 000	2, 000
	22	18	2	Student	-------	3, 000	1, 000
	23	51	30	Spiritualist	3, 500	7, 000	3, 500
	24	35	13	Housewife	4, 000	8, 000	3, 000
	25	20	5	Student	5, 000	1, 000	6, 000

What criteria should be employed in determining the critical distance at which an opposing vehicle is brought to the attention of the passing driver?

Will drivers employ other distance information about opposing vehicles in addition to the *critical distance?*

Will drivers use opposing vehicle speed information in making a passing maneuver?

Will drivers use time-to-meeting information in making a passing maneuver?

How long does it take drivers to adapt to the new system?

What instructions should be given to drivers to make it easy for them to learn how to use the new system?

What criteria should be employed in determining how far apart the vehicle detectors shall be?

Are there any side effects and reliability considerations that may affect the operation of the new system—driveways, cross roads, opposing cars passing other opposing cars, steep gradients, stopped vehicles, etc.?

How will environmental conditions—rain, snow, ice, darkness—affect system operations and how can they be overcome?

What will be the costs and the benefits of a passing aid system?

Should information be given to drivers in visual, auditory, or tactile form?

Preliminary answers to some of these quesons were obtained from experimental work ith the PAS I system reported here. Howver, most of the questions will be answered uring PAS II operations.

Objectives of PAS I Study

The initial objectives of the first experiients with PAS I were as follows:

To determine whether drivers, even though their sight distance is restricted, will pass when they are informed that there are no opposing vehicles within a specific distance.

- To ascertain that drivers will use speed information about the opposing vehicle to aid them in passing.
- To obtain an indication of how long it takes drivers to adapt to a new system with one set of instructions.
- To determine whether clearance distances between passing and opposing vehicles at the end of passing maneuvers are adequate, based on use of 1,300-foot signal distances.

The results of experiment 1 indicated that drivers will make selective use of passing aid information given to them by electronic means. Additional planning of more sophisticated passing aid systems is now well underway.

Description of PAS I

The first experiment was based on the use of a mockup of the Passing Aid System. The mockup, called PAS I, was installed on the access road to the Fairbank Highway Research Station and covered a distance of approximately 0.7 mile. A simplified sketch of the PAS I test setup is shown in figure 1.

The west bound direction road was used for the passing maneuver in which one vehicle, the passing car, was to overtake and pass another vehicle, the lead car, according to coded messages issued by the electronic passing aid system. The eastbound lane was used as the opposing lane in which an oncoming vehicle, the opposing car, approached the two westbound vehicles in the east lane to provide a situation that required the driver of the passing vehicle to execute the passing maneuver in time to avoid a collision or to stay in his lane behind the lead car. Sight restrictors, installed along the roadway, obstructed the driver's view of the road ahead and simulated the *blind* condition on 2-lane rural highways caused by hills and curves. Traffic detectors were spaced 44 feet apart in the lane used by opposing vehicles, and as the opposing vehicle moved over each detector, an intermittent audible signal was transmitted. The intermittent signal, which could be received by the passing car, was detectable at any point within 1,300 feet ahead of the opposing vehicle.

Four conditions could exist for the driver of the passing car: (1) No signal—the system was not operating, (2) a steady uninterrupted signal—the opposing lane was clear of traffic for at least 1,300 feet, (3) the beginning of an intermittent signal—there was a moving vehicle 1,300 feet ahead in the opposing lane, and (4) repetition of the intermittent signal—a moving vehicle was within 1,300 feet ahead in the opposing lane. The frequency/second of the intermittent signals increased with the speed of the opposing vehicle. After the beginning of the signal, the number of intermittent signals and the speed of the opposing vehicle indicated the clearance distance between the two vehicles.

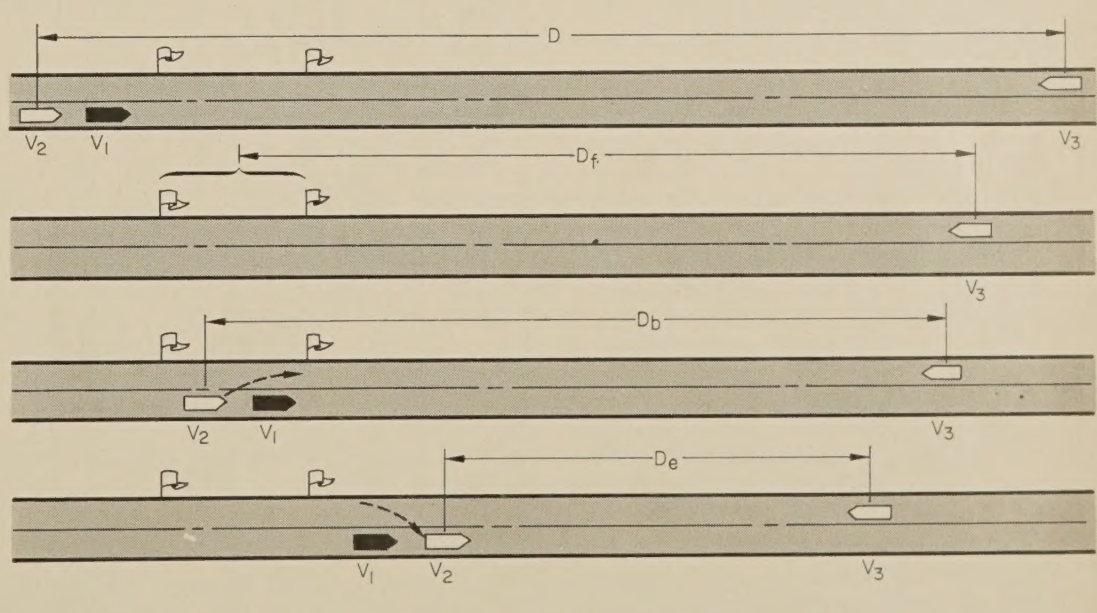

Figure 2.—Diagrammatic representation of variables.

Test Subjects and Vehicles

Test subjects used in the two experiments were obtained from the student body of George Washington University, the Bureau of Public Roads staff and the general public. Information about the drivers is shown in table 1.

The passing and opposing vehicles driven by the test subjects were 1967 4-door sedans—Dodge, Valiant, and Plymouth—with the following specifications: automatic transmission, power steering, power brakes, 6 cylinder, 225-cu. in. cylinder displacement, and 145-brake horsepower.

Table 2.—Minimum passing-sight-distance for design of 2-lane highways [1]

Design speed	Assumed passing speed	Minimum passing-sight-distance
m.p.h.	*m.p.h.*	*feet*
30	30	800
40	40	1,300
50	48	1,700
60	55	2,000
70	60	2,300

[1] Source: Blue Book, *Geometric Design Rural Highways*, 1959, p. 211.

The lead car used in experiment 1 was a 1966 4-door Ford sedan with automatic transmission. The lead car in experiment 2 was a 1967 4-door Mercury sedan with automatic transmission, power steering, power brakes, 200-brake horsepower, 8 cylinders, and cylinder displacement of 289 cu. in. In general, the test drivers considered the power and performance of the vehicles they drove to be adequate.

The combination of the driver and the vehicle he drove for the first time presented significant variables that were significant in determining the acceptance of a passing aid system.

Description PAS I Study Variables

The variables considered in the preliminary studies are itemized in the following list, and where applicable, they are shown in figure 2:

Distance

- D = distance between passing and opposing car.
- D_s = signal range generated ahead of opposing car, 1,300 feet.
- D_f = D where passing may begin—anywhere between the two flags.
- D_b = D when passing maneuver begins.
- D_e = D where passing maneuver ends.

Speed

- V_1 = speed of lead car.
- V_2 = speed of car following lead car prior to passing maneuver.
- V_3 = speed of opposing car.

Time

- T_p = time required to pass.
- T_j = time for test car to reach juxtaposition with opposing car after having completed passing maneuver.

Time, in addition to distance and speed, was observed in the hope that it would serve as a check—distance = speed × time—and be useful for the period covered by the passing maneuver when acceleration and speeds change significantly.

Two types of test runs were used in the experiments—*radio* and *control*. In the *radio*, or PAS I, test runs, the electronic passing aid system was used by the driver of the passing car to overtake and pass the lead car. The *control* test runs were made without the use of the passing aid system and were included in the experiments to provide a basis of comparison in analyzing the effectiveness of PAS I. The 2-lane test roadway had a design speed of 70 m.p.h., a posted speed limit of 30 m.p.h., and two long, 3-degree curves with a tangent between them. The posted speed limit was not in effect for the test runs.

Discussion of Variables

Preliminary test data, collected prior to experiments 1 and 2, indicated that several variables would have to be controlled.

The first variable was sight distance. Sight distances were so large it would have been difficult to determine whether there was any difference in the frequency of passing maneuvers between the control and simulated PAS I test runs. To decrease passing opportunity and more closely simulate driving conditions that would exist on a rural mountainous road, temporary panels were installed (see fig. 1) to restrict the sight distance. To insure comparable passing opportunities for the test and control situations, the sharpest curve, near the midpoint of the test road, was used. The part of the curve between stations 150 and 125 was selected as the section of roadway where passing maneuvers could begin. Here sight distances were 620–1,300 feet, bu temporary panels reduced them to 400–55(feet. The sight distance was based on th ability of the driver in the right lane to se any part of a vehicle in the opposing lane

The second variable to be controlled wa the frequency at which an opposing vehicl was encountered in the passing area. For th control phase of preliminary test runs, driver were instructed to drive the way they nor mally drive, but the frequency of passin maneuvers seemed abnormally high. Tes drivers confirmed this by volunteering th information that normally, on the open high way, they would not pass if the sight distanc were comparable.

Three possible reasons were considered fo the incongruity between drivers' statemen and actions. The first was that the test roa was always cleared of other traffic so th passing manuevers could be based solely o the position and speed of the opposing te vehicle. This was a definite requirement fo study of PAS I and consequently, to perm a comparison, it was also a requirement fo the control phase. Because test drivers kne there would be only one vehicle in the opposin lane and that the driver of the opposing c would be aware of the passing maneuver, the were more willing to pass. They apparent believed that they were not fully responsib for the passing maneuver and its possible co sequences, as they are on the open road.

Another possible reason for the discrepan between the statements and actions of t drivers was that they were speaking in gener terms based on normal operating speeds. F example, table 2 gives minimum passing sig distances of 800 and 1,300 feet at speeds

PASSING AID SYSTEM I — EXPERIMENT NO. 1 — FIELD DAT

Test Subject:______ Observer:______ Date:______ Time Begin:______

Run No.	Series	Passing car (m.p.h.)	Opposing car m.p.h.	Opposing car Start Station	Station Number (Units=passing car. Tens=opposing car. Twenties=passed car) m_1	m_2	m_3	m_4	m_{11}	m_{12}	m_{13}	-	m_{23}	-	Time-0.01 min. t_1 = zero t_2	t_3	t_4	Remark
1	CONTROL	30	15	88	151	149	135	115	105	106	111		132		2.5	9	28	PASS
2	"	45	45	27	150			102	57								30	NO PASS
3	"	45	15	88														
4	"	30	45	88														
5	RADIO CONTROL	30	45	27														
6	"	30	15	88														
7	"	45	45	27														
8	"	45	45	50														
9	"	45	15	88														
10	"	30	45	27														
11	"	30	15	50														
12	"	30	15	88														
13	"	45	15	88														
14	"	45	45	50														
15	"	45	45	27														
16	"	30	45	27														
17	CONTROL	30	15	88														
18	"	45	45	27														
19	"	45	15	88														
20	"	30	45	27														

Figure 3.—Sample data sheet, experiment No. 1.

0 and 40 m.p.h. respectively. If these speeds were considered normal, it would have been unsafe to pass after installation of the temporary sight-restrictor panels, because the maximum sight distance available in the designated passing area was less than 550 feet. At 20 m.p.h., however, the minimum passing sight distance would have been approximately the same as the sight distance available, and the test subjects should have been willing to pass with or without the use of PAS I. The preferred approach was to study conditions in which passing maneuvers normally were not feasible, and it was decided to eliminate test runs based on a lead car speed of 20 m.p.h.

A third possible reason for the incongruity between drivers' statements and actions was that the opposing vehicle and the passing vehicle seldom were near the passing area simultaneously, and drivers may have realized that it was usually safe to pass the lead car.

Any of these possibilities or combinations of them, could have accounted for the high passing frequency in the control phase of the preliminary tests. To eliminate the first possibility, decreased driver responsibility, the following driving instructions were issued to the test subjects; these instructions replaced the game aura of the experiment with one of responsibility:

Entering the car.—"Please fasten your safety belt. The purpose of this research study is to analyze how you drive so we may develop aids to other drivers."

Test runs, control phase.—"Please start the car. Drive as you normally would on this 2-lane highway. Follow the car ahead. There will be traffic coming toward you in the opposing lane. If in your judgment you would normally pass the car ahead, you are free to do so by beginning your passing maneuver somewhere between the two red flags along the left side of the road. If you do not consider it safe to pass, continue to follow the car ahead. Drive safely. Take no chances. Drive in a manner similar to the way you drive on the highway. Any questions?"

Test runs, passing aid phase.—"When you hear a continuous tone, from your radio receiver, the opposing lane is clear of moving traffic for at least ¼ mile. When a vehicle is moving toward you in the opposing lane closer than ¼ mile, you will hear beeps on the radio. If you desire to pass, you may use the radio signals to aid you in deciding whether or not to pass.

"As before, if you do choose to pass the car ahead, the passing maneuver should start in the area between the red flags. Any questions?"

The second possibility was eliminated by discarding the 20-m.p.h. test runs, mentioned earlier, and the third by increasing, for each test subject, the percentage of runs in which there was no opportunity to pass in the passing area. For the *no-passing* situation to occur in the designated passing area, it was necessary to specify not only the lead car and opposing vehicle speeds, but also the stations from which the vehicles would begin each test run.

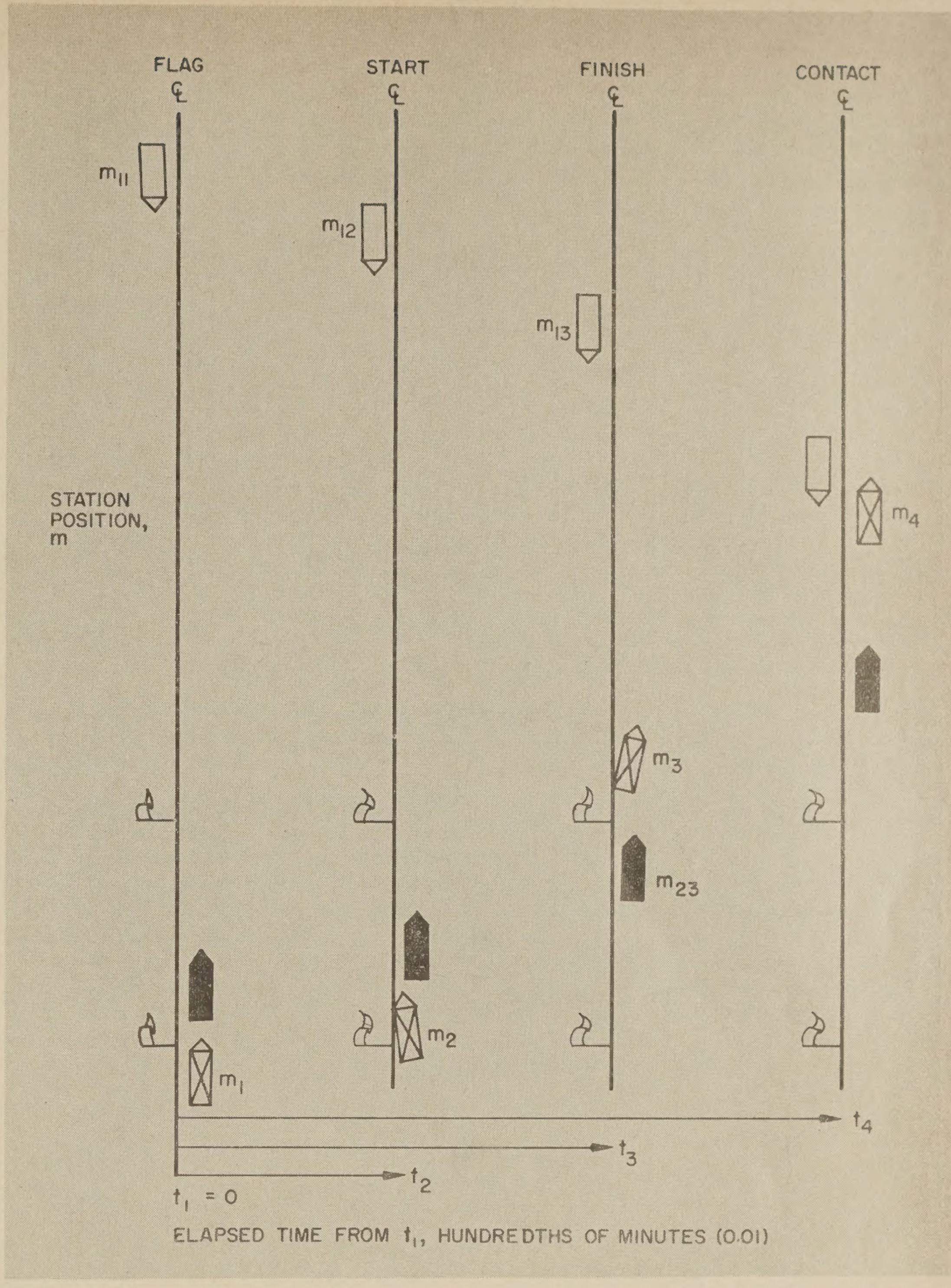

Figure 4.—Vehicle positions at which station numbers and elapsed time was recorded.

Experiments and Procedure

Data were collected in two series of tests—experiment 1 and experiment 2. In both experiments the test subjects were used in pairs. For a test run, one subject would operate the passing vehicle and the other subject the opposing car. For the next test run, the drivers exchanged assignments so that each driver was used coming and going in each pair of runs.

Experiment 1

Data for experiment 1 were recorded on the form shown in figure 3. The first five vertical columns at the left contain the previously discussed control variables. The *run number* indicates the individual trips on the test road during which a passing maneuver could occur. The column originally indicated the trip sequence for both drivers, but midway through experiment 1, this arrangement was determined to be undesirable, as one driver of each pair of drivers would operate the opposing vehicle in one run, then operate the passing vehicle in the next run under identical test conditions. Consequently, he could recall the starting position of the opposing vehicle, its speed, the clearance distance available for passing, or any one of these factors, to formulate a predetermined pass or no-pass decision. In the field it was decided to eliminate the

Table 3.—Data summary for experiment 1, test subjects Nos. 12–17 [1]

Speed combination		Begin run		Opposing lane clear for more than 1,300 ft. at 1st flag	Pass/No-pass frequency				Passing percentage			
					Control		PAS I		Control		PAS I	
Lead car	Opposing car	Lead car	Opposing car		Pass	No-pass	Pass	No-pass	Test	Total	Test	Total
m.p.h.	*m.p.h.*	*Station No.*	*Station No.*		*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*
30	15	180	27	Yes	2	2	1	0	50	------	100	------
		180	50	Yes	0	0	6	2	------	------	75	------
		180	88	No	4	3	3	5	57	------	38	------
				Total passing percent	------	------	------	------	------	55	------	59
30	45	180	27	Yes	2	2	12	3	50	------	80	------
		180	50	No	0	0	0	0	------	------	------	------
		180	88	No	1	5	1	0	17	------	------	------
				Total passing percent	------	------	------	------	------	30	------	81
45	15	180	27	Yes	0	0	0	0	------	------	------	------
		180	50	Yes	0	0	0	0	------	------	------	------
		180	88	No	1	7	1	6	12	------	14	------
				Total passing percent	------	------	------	------	------	12	------	14
45	45	180	27	Yes	3	3	7	3	50	------	70	------
		180	50	Yes	0	0	5	4	------	------	56	------
		180	88	No	0	5	1	1	------	------	50	------
				Total passing percent	------	------	------	------	------	27	------	61
				Total observed data	13	27	37	24	------	32	------	61

[1] Test subjects are listed in table 1.

Table 4.—Data summary for experiment 2, test subjects Nos. 18–23 [1]

Speed combination		Begin run		Opposing lane clear for more than 1,300 ft. at 1st flag	Pass/No-pass frequency				Passing percentage			
					Control		PAS I		Control		PAS I	
Lead car	Opposing car	Lead car	Opposing car		Pass	No-pass	Pass	No-pass	Test	Total	Test	Total
m.p.h.	*m.p.h.*	*Station No.*	*Station No.*		*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*
30	15	180	27	Yes	2	4	4	2	33	------	66	------
		180	88	No	0	6	2	4	0	------	33	------
				Total passing percent	------	------	------	------	------	17	------	50
30	45	180	27	Yes	1	5	5	1	17	------	83	------
		180	88	No	2	4	1	5	33	------	16	------
				Total passing percent	------	------	------	------	------	25	------	50
45	15	180	27	Yes	0	6	0	6	0	------	0	------
		180	88	No	0	6	0	6	0	------	0	------
				Total passing percent	------	------	------	------	------	0	------	0
45	45	180	27	Yes	0	6	1	5	0	------	16	------
		180	88	No	0	6	0	6	0	------	0	------
				Total passing percent	------	------	------	------	------	0	------	8
				Total observed data	5	43	13	35	------	10	------	27

[1] Test subjects are listed in table 1.

Table 5.—Data summary for experiments 1 and 2 combined, test subjects Nos. 12–17 and 18–23 [1]

Speed combination		Begin run		Opposing lane clear for more than 1,300 ft. at 1st flag	Pass/No-pass frequency				Passing percentage			
					Control		PAS I		Control		PAS I	
Lead car	Opposing car	Lead car	Opposing car		Pass	No-pass	Pass	No-pass	Test	Total	Test	Total
m.p.h.	*m.p.h.*	*Station No.*	*Station No.*		*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*
30	15	180	27	Yes	4	6	5	2	40	------	71	------
		180	88	No	4	9	5	9	31	------	36	------
				Total passing percent	------	------	------	------	------	35	------	48
30	45	180	27	Yes	3	7	17	4	30	------	81	------
		180	88	No	3	9	2	5	25	------	29	------
				Total passing percent	------	------	------	------	------	27	------	68
45	15	180	27	Yes	0	6	0	6	0	------	0	------
		180	88	No	1	13	1	12	7	------	8	------
				Total passing percent	------	------	------	------	------	5	------	5
45	45	180	27	Yes	3	9	8	8	25	------	50	------
		180	88	No	0	11	1	7	0	------	12	------
				Total passing percent	------	------	------	------	------	13	------	37
				Total observed data	18	70	39	53	------	26	------	74

[1] Tests subjects are listed in table 1.

ossibility of predetermined decisions by a ındom selection of each succeeding test run om those remaining to be made. Accordingly, ıe data in experiment 1 were considered to be ee of predetermined pass or no-pass decisions.

In the second column of figure 3, *control*, ıeans without the use of the passing aid sysem, and *radio*, means with use of the passing id system. The data under *pass. car* are the peeds of the lead car and passing car prior to arting the passing maneuver. The speed of ıe opposing car and the station from which it arted are given in the next two columns for ıch test run. In all test runs, the lead car nd the test vehicle started from a stationary osition at station 180. The results of preminary test runs, before PAS I was oprational, were the basis for determining the reselected variables.

The instrumentation for the experimental rocedure was simple. Distances were deterıined by relating vehicle positions to the elecronic detector stations numbered consecuvely from the west end of the test road; ations were 22 feet apart. Speeds for the ad car and the opposing car were preselected, nd the drivers accelerated to the constant peeds and maintained them by referring to ıe speedometer in the vehicles. Two-way ıdios were used to communicate among the ıree vehicles and disseminate the following ıformation: *road clear*, meaning the route is ear for the test run; *flag*, meaning the beginning of the length of roadway where a passing ıaneuver could be initiated; *start*, meaning ıe driver has started the passing maneuver; nd *finish*, meaning the driver has completed ıe passing maneuver and has returned to the ght lane. The relations between vehicle posiions and elapsed times are shown in figure 4. he term *contact*, shown at time t_1, means that ıe passing vehicle and the opposing vehicle re at the same position on the roadway after ompletion of the passing maneuver.

In figure 3, m_1, m_2, m_3, and m_4 are the ation locations of the test vehicle at *flag*, *tart, finish*, and *contact* respectively; m_{11}, m_{12}, nd m_{13} are the station locations of the oppos-ıg car when the passing car signals *flag, start*, nd *finish;* and m_{23} is the recorded position f the lead car at the finish signal. In the time olumns of figure 3, t_2, t_3, and t_4 are the lapsed times in hundredths of a minute (0.01) om *flag* to *start, finish*, and *contact*, respecvely.

xperiment 2

Experiment 2 was basically a continuation f experiment 1, but was different in two espects: (1) Pass or no-pass signals, that could e increased in volume and include an accomanying light signal on the dashboard of the ar, were provided for the drivers, (2) The umber and distribution of runs, were adjusted ccording to control variables so that there ould be matching *control* and *radio* (PAS I) ıns.

The predetermined orders of runs for experiıent 2, which were based on the theory of andom numbers, are shown in figures 5 and 6. hese two orders, A series and B series, eliminated possible bias that could have occurred if the test runs had been selected in the field, and decreased the possibility that drivers would know the position of the opposing car. Test runs in A series and B series were similar, only the sequence was different.

The percentage of test runs that were passing maneuvers in the control and PAS I phases are shown in figures 8, 9, and 10 respectively for experiment 1, experiment 2, and experiments 1 and 2 combined. Data points on the graphs are the percentage subtotals shown on tables 3, 4, and 5. For example, in table 6 and figure 8 it is shown that for a lead car speed of 30 m.p.h., an opposing car speed of 15 m.p.h., and three opposing car starting stations, 55 percent of the control test runs were passing maneuvers. To make valid comparisons of passing percentages between the control and PAS I phases, the proportions of the runs assigned to the different opposing car starting stations would have to be equal for both

PASSING AID SYSTEM I — EXPERIMENT NO. 2 — FIELD DATA

Test Subject: ______ Observer: ______ Date: ______ Time Begin: ______

Run No.	A Series	Lead & passing car (m.p.h.)	Opposing car m.p.h.	Opposing car Start Station	Station Number (Units=passing car. Tens=opposing car. Twenties=passed car) m_1	m_2	m_3	m_4	m_{11}	m_{12}	m_{13}	–	m_{23}	–	Time–0.01 min. t_1 = zero t_2	t_3	t_4	Remarks
1	CONTROL	45	15	88														
2	"	30	45	27														
3	"	30	15	27														
4	"	45	15	27														
5	RADIO	45	15	27														
6	"	30	15	27														
7	"	30	45	27														
8	"	30	15	88														
9	"	30	45	88														
10	"	45	45	88														
11	"	45	45	27														
12	"	45	15	88														
13	CONTROL	30	45	88														
14	"	30	15	88														
15	"	45	45	88														
16	"	45	45	27														
17																		
18																		
19																		
20																		

Figure 5.—Sample data sheet, experiment No. 2, Series A.

PASSING AID SYSTEM I — EXPERIMENT NO. 2 — FIELD DATA

Test Subject: ______ Observer: ______ Date: ______ Time Begin: ______

Run No.	B Series	Lead & passing car (m.p.h.)	Opposing car m.p.h.	Opposing car Start Station	Station Number (Units=passing car. Tens=opposing car. Twenties=passed car) m_1	m_2	m_3	m_4	m_{11}	m_{12}	m_{13}	–	m_{23}	–	Time–0.01 min. t_1 = zero t_2	t_3	t_4	Remarks
1	CONTROL	45	45	27														
2	"	45	15	88														
3	"	30	45	88														
4	"	30	15	27														
5	RADIO	30	45	88														
6	"	30	15	88														
7	"	30	45	27														
8	"	30	15	27														
9	"	45	15	27														
10	"	45	15	88														
11	"	45	45	88														
12	"	45	45	27														
13	CONTROL	30	45	27														
14	"	30	15	88														
15	"	45	15	27														
16	"	45	45	88														
17																		
18																		
19																		
20																		

Figure 6.—Sample data sheet, experiment No. 2, Series B.

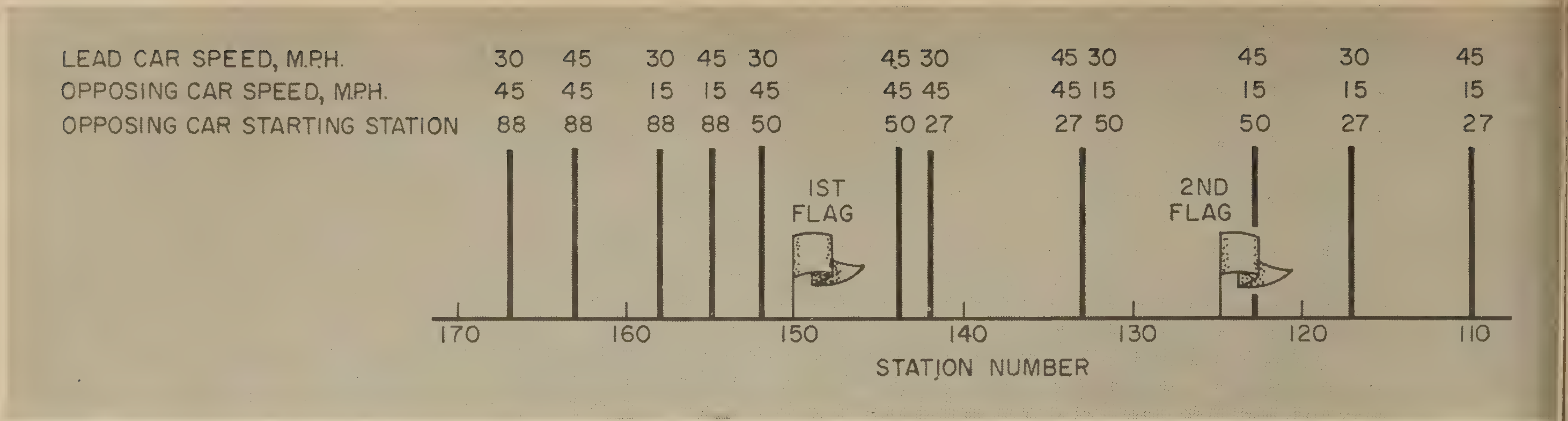

Figure 7.—Estimated position of passing car at which signal from opposing car would first be received.

phases. This requirement was met for experiment 2 (fig. 9) but was not for the other experiments, which may explain the possible misalinement of the control phase curves of figure 8. The data in all three figures indicate the apparent increased percentage of test runs having passing maneuvers for transitions from the control phase to the PAS I phase.

Statistical Tests

Chi square tests and confidence limit intervals were used to determine the statistical significance of the results. An advantage of the chi square test is the *yes* or *no* answer obtained. However, in situations where data do not meet minimum requirements, the chi square test is not applicable. Confidence limit bands can be based on any size sample, but conclusions can vary with interpretation of the bands. Both approaches were used with emphasis given to the one considered most applicable to the particular analysis being made.

Chi square tests

The chi square statistic takes into account the similarities of samples that occur by chance alone, regardless of whether the samples are from the same or different populations. A calculated value of the chi square, based on observed data, can be compared to standard tabulated values of chi square shown in textbooks on statistics (*1*).[1] Depending on the percentage level of confidence desired, the comparison can infer whether any difference in two samples is likely to have occurred by chance alone. If an existing difference did not occur by chance alone, then the difference is significant.

The chi square tests used in this report were based on the use of 2 × 2 tables (1 degree of freedom), and a tabulated value of chi square equal to 3.84 for the 95-percent confidence level. The 95-percent confidence level is commonly used and accepted in research.

Confidence intervals

To estimate the mean of a population, it is helpful to have not only a sample mean but also a measure of the margin of error of the sample mean. A way to do this is to specify a zone, based on the sample mean, within which the population mean lies. This zone is called a confidence interval, and the end points of this interval are called confidence limits. The probability that the interval will include the population mean is stated as a percentage and is referred to as the confidence level. The 95-percent confidence level was used in the research reported here.

The control phase of the experiments was the population, or real world, used as a basis of comparison. Because the control phase was also a sample, the test basically was a com parison of two sample intervals. If the range of the two confidence intervals were generall similar, the samples were from the sam population. If the ranges of the confidenc intervals were generally different, then th samples were from different populations.

Confidence limits for each proportion wer obtained from an Ordnance Engineering De sign Handbook (*2*). The upper and lower cor fidence limits were obtained from tables fo samples of fewer than 30 observations an from graphs requiring interpolation for sam ples of more than 30 observations.

The results of the statistical tests have bee assembled as *yes* or *no* answers to question given in table 6.[2] For example, if a statistica test determined that a slight increase in pas ing frequency was insignificant, the answer i

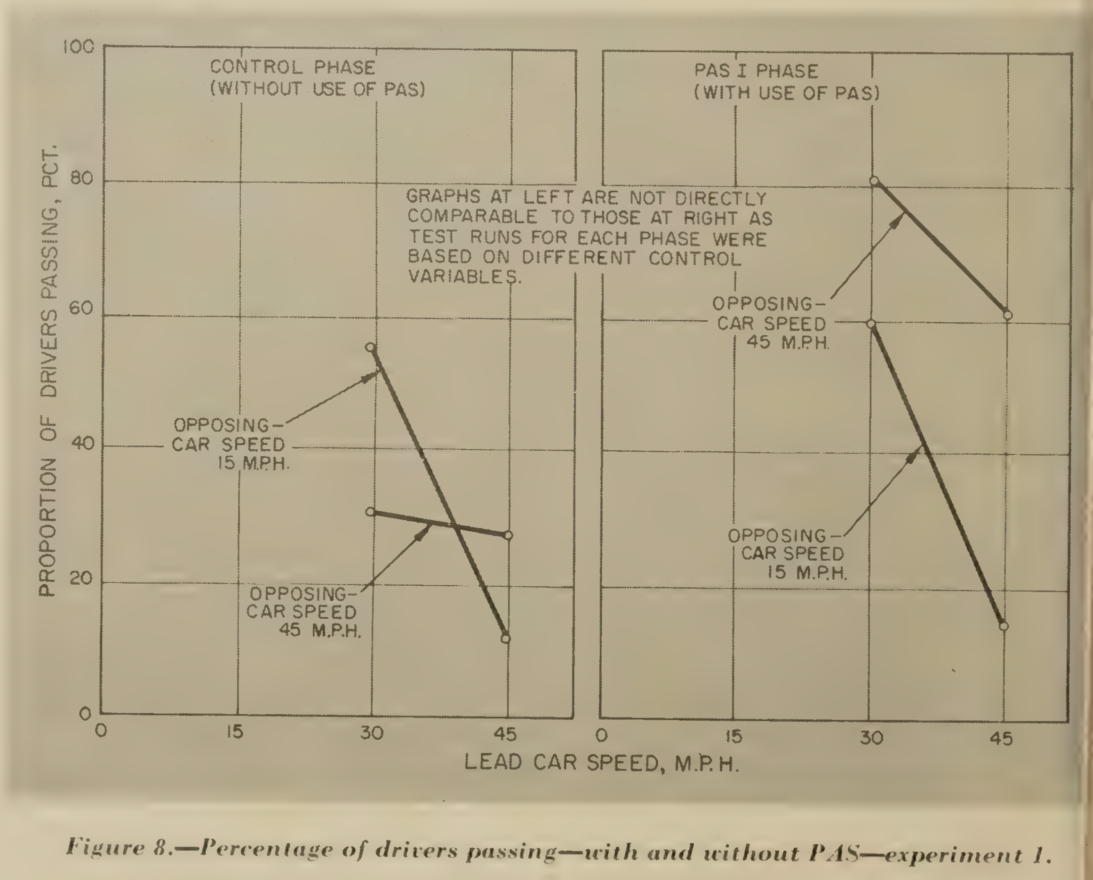

Figure 8.—Percentage of drivers passing—with and without PAS—experiment 1.

[1] The italic numbers in parentheses identify the references listed on p. 76.

[2] Statistical tests that were made for each analysis have been assembled and are available from the Office of Research and Development, Bureau of Public Roads, % Managing Editor, *Public Roads* Magazine.

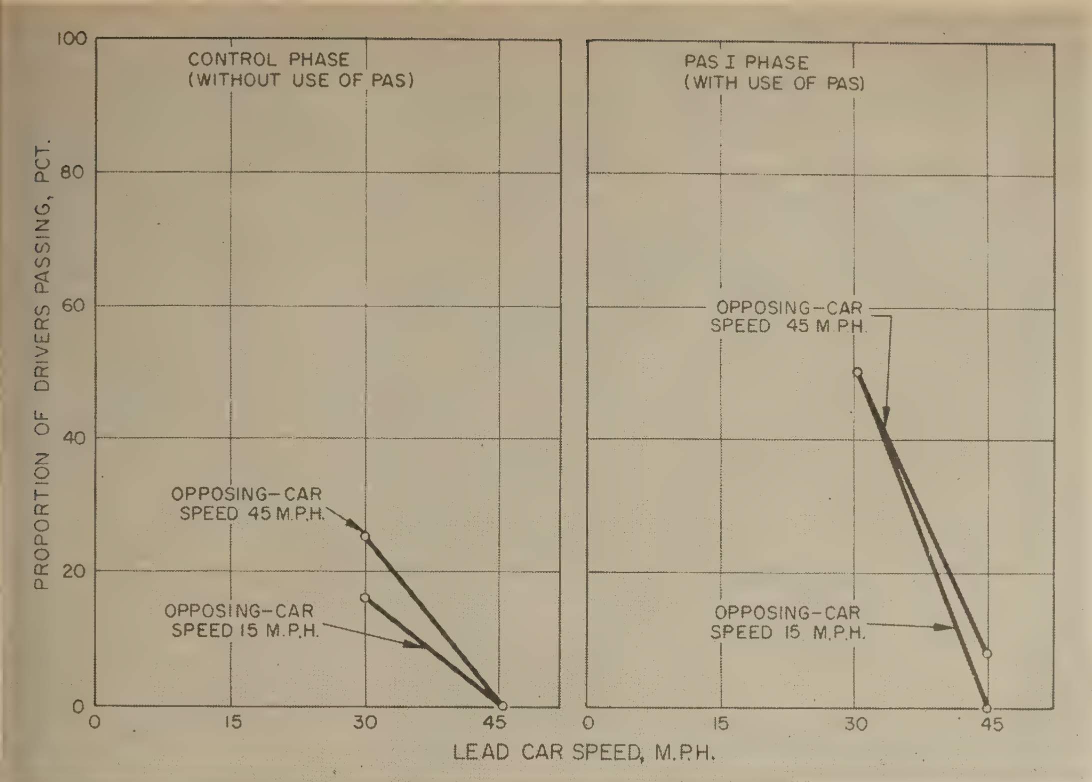

Figure 9.—Percentage of drivers passing—with and without PAS—experiment 2.

table 6 and in the following discussion would state that there was no increase in passing frequency.

Analyses of Statistical Data

A summary of the analyses of the primary data, frequency of passing maneuvers, is given in table 6. The analysis number at the left is followed by the question that the analysis poses. Answers to the question, based on use of the chi square test and confidence intervals for each experiment, are indicated in the columns at the right.

Experiment 2 was the only experiment that had proportionate distribution of test runs with regard to the control variables for each sample. Comparisons of data for experiment 2 were therefore favored over those for experiment 1 and 1 and 2 combined.

Analysis 1

The first analysis was made to determine whether PAS I, compared to the control phase, increased the percentage of passing. The comparison for each experiment was based on all data. Each statistical test applied to the different experiments indicated that use of PAS I did increase the percentage frequency of passing maneuvers.

Analysis 2

The analysis of PAS I, compared to the control phase for lead car speeds of 30 m.p.h., and all the statistical tests used, indicated that PAS I increased the passing percentage.

Analysis 3

Compared to the control phase for lead car speeds of 45 m.p.h., the analysis of PAS I failed to show conclusively that it increased passing percentage. Chi square tests were limited because of sample distribution and/or the minimum data criteria for the test. The use of confidence intervals indicated that PAS I increased passing percentage for experiment 1 and 1 and 2 combined, both of which were unbalanced samples. The one reliable test for this analysis, the use of confidence limits on experiment 2, indicated that PAS I did not increase passing percentage.

Analysis 4

The analysis, based solely on the use of PAS I indicated that when lead car speed was increased from 30 to 45 m.p.h., there was a decrease in passing frequency. The statistical tests based on experiment 1 produced answers to the contrary, or answers with doubtful conclusions because of the unbalanced sample distribution. Experiment 2, with balanced sampling, produced the most reliable conclusions which were supported by the conclusions from the combined data of experiments 1 and 2. The accepted conclusion is reasonable, considering the fact that as traffic speed increased, fewer passing maneuvers were required to maintain desired speed.

Analysis 5

When signaled clearance distance at the first passing opportunity was more than 1,300 feet, the analysis of PAS I indicated an increase in passing frequency with the use of PAS I, when compared to the control phase. The statistical tests were in agreement for each of the experiments.

Analysis 6

When signaled clearance distance was less than 1,300 feet, the analysis of PAS I compared to the control phase indicated no change in passing frequency. Statistical tests were in agreement for all experiments, though it should be noted that data were below the minimum required for chi square tests in experiments 1 and 2.

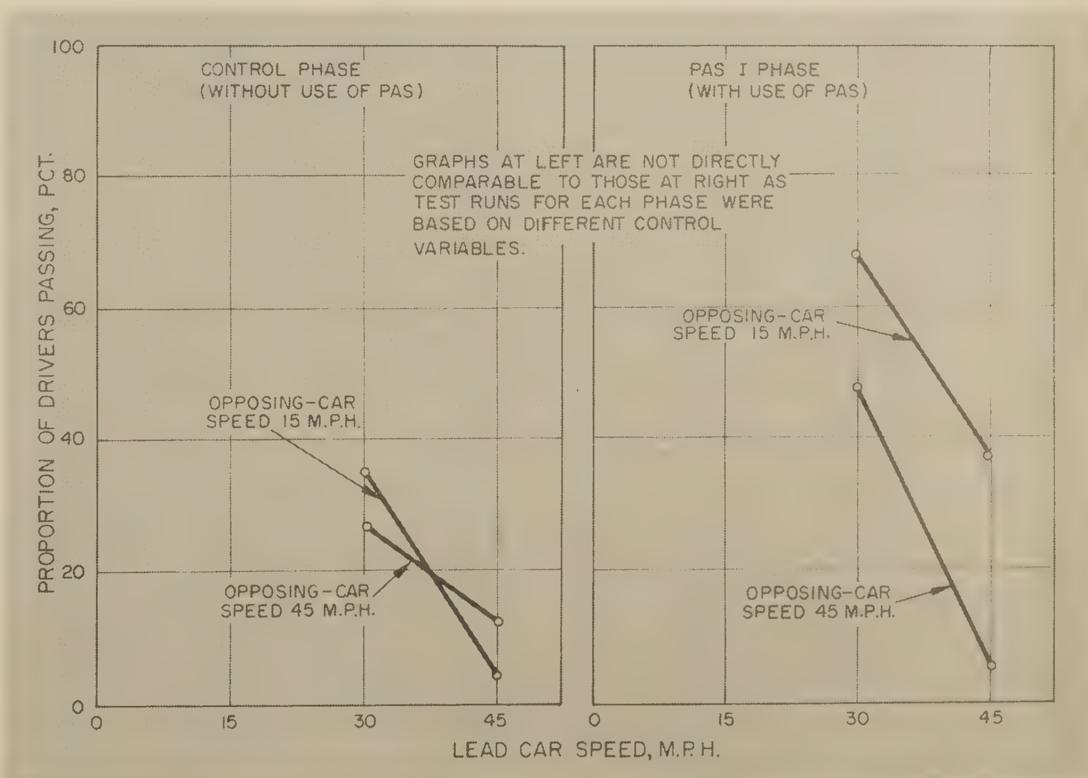

Figure 10.—Percentage of drivers passing—with and without PAS—experiments 2 and 3 combined.

Table 6.—Results of statistical tests

Analysis No., description, and question	Answers for each experiment: Chi square test, 1[1]	Chi square test, 2	Chi square test, 1 and 2[1] combined	Confidence interval, 1[1]	Confidence interval, 2	Confidence interval, 1 and 2[1] combined
1 Did PAS I, compared to control phase, show larger percentage of passing?	yes	yes	yes	yes	yes	yes
2 Did PAS I, compared to control phase for lead car speed of 30 m.p.h., show larger passing percentage?	yes	yes	yes	yes	yes	yes
3 Did PAS I, compared to control phase for lead car speed of 45 m.p.h., show larger passing percentage?	yes	(2)	yes	yes	no	yes
4 Did passing percentages decrease with use of PAS I and increase in lead car speed (30-45 m.p.h.)?	no	yes	yes	?	yes	yes
5 Did PAS I, compared to control phase, increase passing percentage when signal clearance exceeded 1,300 ft.?	yes[2]	yes	yes	yes	yes	yes
6 Did PAS I, compared to control phase, give similar passing percentage when signal clearance was less than 1,300 ft.?	yes[2]	(2)	yes	yes	yes	yes
7 Did PAS I, compared to control phase show increase in passing for:						
a Lead car speed of 30 m.p.h., opposing car speed of 15 m.p.h., opposing car starting station 27						yes
b Lead car speed of 30 m.p.h., opposing car speed of 15 m.p.h., opposing car starting station 88[3]						no
c Lead car speed of 30 m.p.h., opposing car speed of 45 m.p.h., opposing car starting station 27						yes
d Lead car speed of 30 m.p.h., opposing car speed of 45 m.p.h., opposing car starting station 88[3]						no
e Lead car speed of 45 m.p.h., opposing car speed of 15 m.p.h., opposing car starting station 27						no
f Lead car speed of 45 m.p.h., opposing car speed of 15 m.p.h., opposing car starting station 88[3]						no
g Lead car speed of 45 m.p.h., opposing car speed of 45 m.p.h., opposing car starting station 27						no
h Lead car speed of 45 m.p.h., opposing car speed of 45 m.p.h., opposing car starting station 88[3]						no

[1] Conclusions weakened by sample distributions.
[2] Does not satisfy criteria for chi square test.
[3] Signaled clearance distance is less than 1,300 ft. when the passing vehicle reaches the permitted passing area.

Table 7.—Clearance distance between passing and opposing vehicles at completion of passing maneuver, experiments 1 and 2 combined

Control variables: Speed of lead car	Speed of opposing car	Beginning station for opposing car	Phase	Test runs: Total	With passes	With passes and data	Average clearance distance
m.p.h.	*m.p.h.*	*number*		*number*	*number*	*number*	*feet*
30	15	27	Control	12	6	6	1,364
			PAS I	8	6	6	1,408
30	15	88	Control	14	5	3	180
			PAS I	14	5	5	374
30	45	27	Control	11	4	3	300
			PAS I	22	18	17	814
30	45	88	Control	13	3	2	0
			PAS I	8	2	1	242
45	15	27	Control	8	0	0	--------
			PAS I	7	0	0	--------
45	15	88	Control	14	1	1	154
			PAS I	13	1	1	132
45	45	27	Control	13	4	3	968
			PAS I	16	8	7	726
45	45	88	Control	10	0	0	--------
			PAS I	8	1	0	--------

Analysis 7

In this analysis the confidence intervals were developed for the control and PAS I phases of eight combinations of lead car speed, opposing car speed, and opposing car starting station. The question for each combination was "does the use of PAS I increase the frequency of passing maneuvers when compared to the control phase?" Results of statistical tests can be categorized as follows:

(1) Those combinations based on the opposing car starting from station 88 showed no increase in passing maneuvers. The signaled clearance distance at the first passing opportunity for each combination was less than 1,300 feet. The findings were in agreement with those of analysis 6.

(2) Those combinations, based on the opposing car starting from station 27, showed an increase in passing maneuvers when the lead car speed was 30 m.p.h. and no increase in passing maneuvers when the lead car speed was 45 m.p.h. The findings were in agreement with those findings of analyses 2 and 3, respectively.

Clearance at End of Passing Maneuvers

One of the objectives of the experiments was to determine whether clearance distance between the passing and opposing vehicle at the end of the passing maneuver, based on use of the 1,300-foot clearance distance, was adequate. Average clearance distances, according to data from combined experiments 1 and 2, are shown in table 7. Data in the table are classified at the left by the control variables: lead car speed, opposing car speed, and opposing car starting station. For both the control and PAS I phases each classification shows the total number of test runs observed, number of test runs that were passing maneuvers, number of test runs with passes for which clearance data were obtained, and average clearance distance between the passing and opposing vehicle at the end of the completed passing manuever.

The use of PAS I when compared to the control phase, based on the lead car speed of 30 m.p.h., increased the clearance distance at the end of the passing maneuvers. For lead car speeds of 45 m.p.h., the clearance distance decreased.

Summary

A full-scale mockup of a Passing Aid System (PAS I) was installed and tested on a short section of 2-lane highway. Results of a limited experiment showed that when sight was restricted to a distance considerably below the 800 feet of passing sight distance required for a design speed of 30 m.p.h. drivers made selective use of passing-distance information given to them electronically. At operating speeds of 30 m.p.h., drivers made significant use of PAS I when clear distances exceeding 1,300 feet were indicated electronically, and the passing percentage was substantially increased (see fig. 9). At 4[5] m.p.h., drivers used PAS I less frequently. The sight distance for passing at 45 m.p.h. is approximately 1,500 feet, but the present design of PAS I provided only 1,300 feet for passing.

The one set of instructions used in these experiments introduced drivers to the passing aid system but did not adapt them to i[t]. Use of the passing aid system is required. Th[e] experience gained was too limited to con[-]clude that the drivers had satisfactorily adap[t]ed to the system.

Based on use of PAS I, clearance distance between the passing vehicle and opposing vehicle at the end of the passing maneuv[er] were adequate when lead car speeds wer[e] 30 m.p.h., but inadequate when lead ca[r] speeds were 45 m.p.h. The control phase wa[s] used as the basis for this conclusion.

Results of the study were favorable for th[e] development and use of passing aid system[s]. Although the range of conditions under which such systems would be useful may not be [as] broad as anticipated, further testing wi[th] passing aid systems is justified.

(*Continued on p. 76*)

Deviation from the mean travel speed on the Interstate System increases the probability of involvement in an accident.

Interstate System Accident Research Study II, Interim Report II

BY THE OFFICE OF
RESEARCH AND DEVELOPMENT
BUREAU OF PUBLIC ROADS

Reported by **JULIE ANNA CIRILLO**,
Mathematician,
Traffic Systems Division

Introduction

THE RESULTS of an analysis of the effects that speed variance among vehicles, level of enforcement, and interchanges have on accident and involvement rates are presented in this report—the second interim report on data collected for the Interstate System Accident Research Study II. The objectives of the research and related study procedures were described in Interim Report I (*1*).[1] The data used in the analysis presented here were collected by 20 State highway departments (see fig. 1).

Speed Variance Among Vehicles

It has been shown in past research that the severity of a given accident will increase as the speed of the vehicles prior to collision increases (*2, 3*). However, the chance of being involved in an accident, at least on 2- and 4-lane main rural highways, having no control of access (*2*), has been shown to be related to speed variance, or deviation from the speed of the traffic stream. It was sought in the analysis reported here to determine whether speed variance contributes to accident involvement on the Interstate System as well. Only accidents occurring between 9 a.m. and 4 p.m. on mainline units were used in the analysis to correspond with the speed data and vehicle classification data collected for the same period. For this study, a mainline study unit is defined as any section of the Interstate highway that is not more than 10,000 feet in length and homogeneous throughout, with respect to its geometric characteristics. Speed data were not obtained during the hours from 4 p.m. to 9 a.m. Speed change lanes, although classified as separate units, were included in the category of mainline units. Ramps, crossroad units, frontage roads, and other units were not included in the analysis. To further reduce the number of variables, 2-lane two-direction mainline study units were eliminated from the analysis; however, both urban and rural sections were studied but were not separated.

In determining the effect of speed variance—not used here in the statistical sense—only rear-end and angle collisions and same-direction sideswipe accidents, occurring between 9 a.m. and 4 p.m., were considered. The assumption was that the effect of vehicular speed differences could best be determined by accidents involving two or more vehicles traveling in the same direction; thus head-on, single vehicle, and pedestrian accidents were not included. Speed data were submitted by the States on EAM (Electronic Accounting Machines) cards in the format shown in figure 2. The coded information represented the percentage of traffic traveling in each speed group. The data were not adjusted in any manner but were used precisely as submitted by the States.

The mean travel speed for each study unit was obtained by accumulating the products of the midspeed for each of the speed groupings—for example, 45 m.p.h. for the speed group 40–49 m.p.h.—and the percentage of the vehicles traveling within the speed group, then dividing the final total by 100. The midspeed used for the *under-40-m.p.h.* speed group was 37.5 m.p.h. for rural areas and 32.5 m.p.h. for urban areas. The midspeeds used for the *80-m.p.h.-or-more* speed group was 85 m.p.h. These midspeeds were determined from speed trend data collected on Interstate highways in many States (*4*).

[1] The italic numbers in parentheses identify the references listed on p. 75.

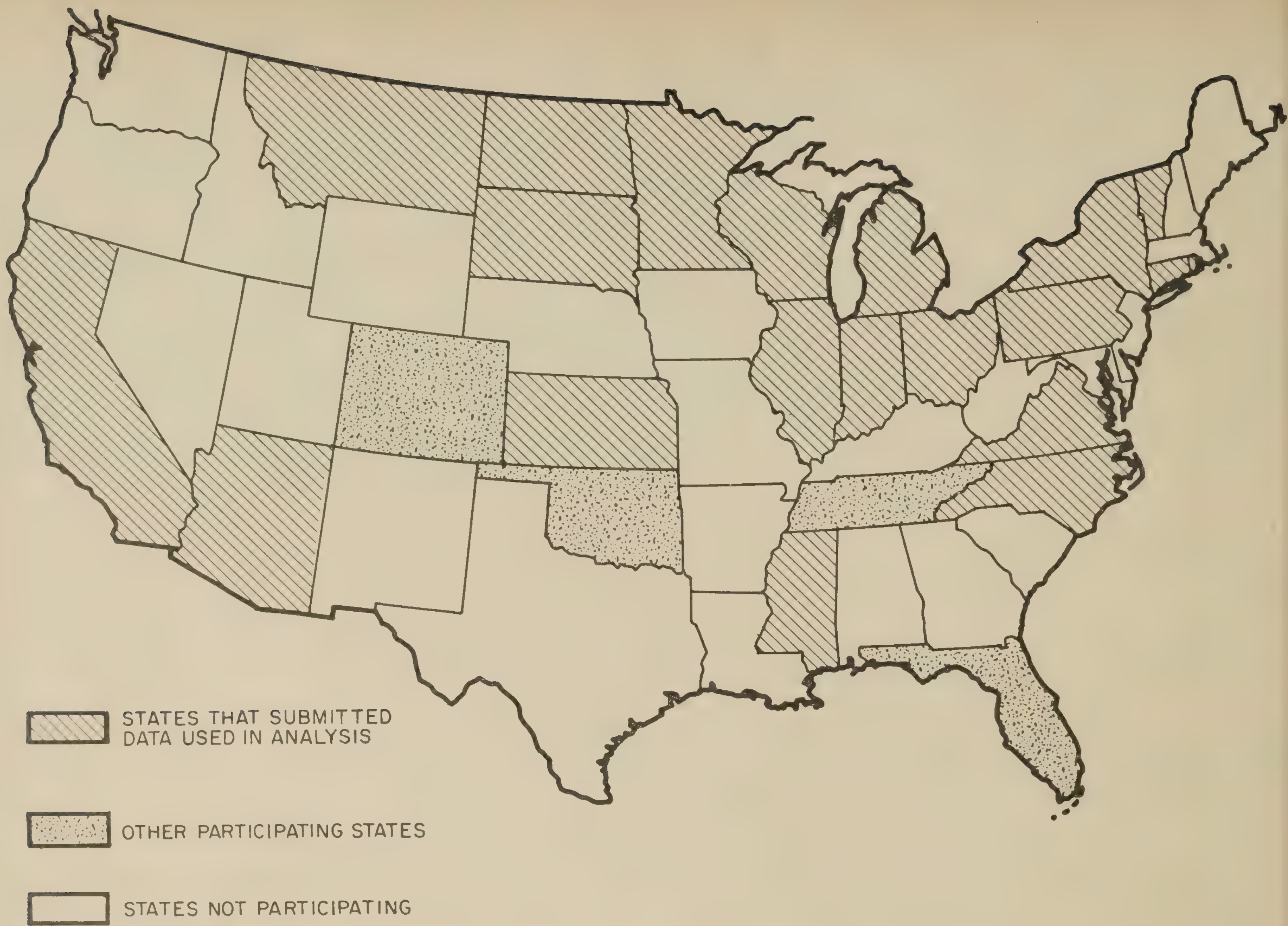

Figure 1.—States participating in Interstate System Accident Research, Study II.

Results of Speed Analysis

Results of the analysis indicated that a reduction in the variation of speed among vehicles should significantly reduce accidents.

The procedure for determining involvement rates, as related to mean speed, was similar to that reported by Solomon for 2-lane and 4-lane rural highways (*2*). Involvement rate is the number of involvements per 100 million vehicle-miles and implies a vehicle involved in an accident. Thus, one accident involving three vehicles is counted as three involvements. The curve shown on figure 3 was plotted on the basis of variation from the mean speed of each unit. The involvement rate at each speed, for each study unit, was related to the variation from the mean speed of the study unit. For each accident that occurred on a study unit being used, the speed of each vehicle involved in the accident was subtracted from the mean speed of the study unit. For example, suppose the mean speed of a study unit was computed to be 60 m.p.h. and a vehicle involved in an accident on this unit was traveling at 55 m.p.h.,[2] then this involvement would be reported as having occurred at a variation of minus 5 m.p.h. from the mean speed. All such data were grouped together to obtain a data point; results of these calculations have been summarized and are shown in table 1. The data points weer plotted on figure 3, in addition to points obtained by Solomon. As these are daytime data, only Solomon's daytime curve was plotted to provide a common basis for comparison.

In table 1, it is shown that the lowest involvement rate occurred at approximately +12 m.p.h. above the mean speed of a study unit. One might expect the lowest involvement rate to occur at the mean speed; but the variation inherent in collecting and estimating speed data is possibly the reason that the lowest involvement rate occurs at +12 m.p.h. above the mean speed. However, as the magnitude of the variation increased, either above or below the mean speed, the involvement rate increased. These results were remarkably similar to those reported by Solomon. This curve is shifted slightly to the right of Solomon's curve (see fig. 3), in which the lowest involvement rate occurred at approximately +8 m.p.h. for daytime accidents; but Solomon's study was conducted on 2-la and 4-lane main rural highways that had control of access. Usually, on this type conventional highway, the average speed lower than on the Interstate highway; mean speed was about 52 m.p.h. on conv tional rural highways and 59 m.p.h. on Int state highways.

[2] Speeds submitted by the State and probably extracted from accident report forms.

Table 1.—Involvement rate by deviati from mean speed

Deviation from mean speed	Involvements	Vehicle-miles	Involvement rat
m.p.h.	*Number*	*Millions*	*Numbe*
−30.0 to −34.9	82	.13	63,222
−25.0 to −29.9	129	1.93	6,673
−20.0 to −24.9	109	14.03	777
−15.0 to −19.9	245	86.86	282
−10.0 to −14.9	259	180.91	143
−5.0 to −9.9	356	519.52	68
0.0 to −4.9	321	755.41	42
+0.1 to +4.9	290	772.84	37
+5.0 to +9.9	162	566.95	28
+10.0 to +14.9	46	180.38	25
+15.0 to +19.9	21	60.13	35
+20.0 to +24.9	14	10.29	136
+25.0 to +29.9	10	3.25	307
+30.0 to +34.9	13	.11	11,627

[1] Involvement rate=number of involvements per million vehicle-miles.

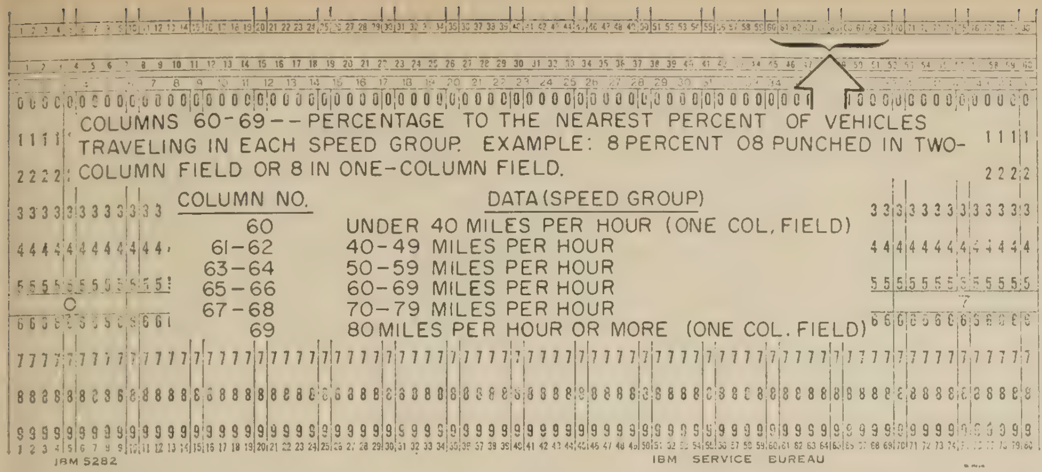

Figure 2.—Speed data collected for Study II.

Results shown in table 2 indicate that no trend can easily be established between an increase in warnings, arrests, or police patrol and the mean speed of travel or the involvement rate on a study section. Further investigation of enforcement related to traffic volume and other variables will be undertaken in the future.

Effect of interchanges on accident rates

In the analysis of the effect of interchanges on accident rates, all units were divided into urban or rural sections. Each mainline unit was then positioned by its proximity to an interchange. Because each unit was located between two interchanges, ahead and behind, accidents were assigned to the nearest interchange. Units equidistant from two interchanges were divided between the two interchanges.

Of more importance is the generally lower ccident rate observed on Interstate highways. lthough the average speed of vehicles on the nterstate System is 7 m.p.h. higher than on onventional main rural roads, the Interstate ystem can better accommodate differences vehicle speeds, with the exception of very ow-moving vehicles. It appears, however, nat with respect to accident involvement on eeways, as well as on conventional rural ghways, both very high and very low speeds e dangerous, and it is differences in speed nong vehicles that cause hazardous situaons. The hazard of slow-moving vehicles on gh-speed highways is indicated by the sharp se in involvement rate for vehicles traveling 5 m.p.h. below the mean speed.

evel of law enforcement

An attempt was made to investigate the fect of the level of law enforcement on mean peed and accident involvement. Data subitted represented the average number of al warnings, written warnings, arrests, and olice patrol hours per mile per year on the nterstate System. Only study sections for hich this information was provided were ed in this analysis. Law enforcement formation was requested for mainline study nits only, but in several States, this information was not available and these sections were ot used in this portion of the analysis.

Enforcement data were collected on an erage daily basis, and speed data were llected for daytime hours only. Therefore, was assumed that the average daily enforcement data were proportional to the level of aytime enforcement. As speed data were llected for daytime hours alone, only those cidents—single and multivehicle—occurring tween 9 a.m. and 4 p.m. were used. The other iteria for the data base in this analysis were e same as the criteria used in the speed alysis—that is, no distinction was made tween urban or rural sections; 2-lane twoection mainline units were eliminated; only ainline units and speed-change lanes were ed, and only traffic volumes between 9 and p.m. were considered.

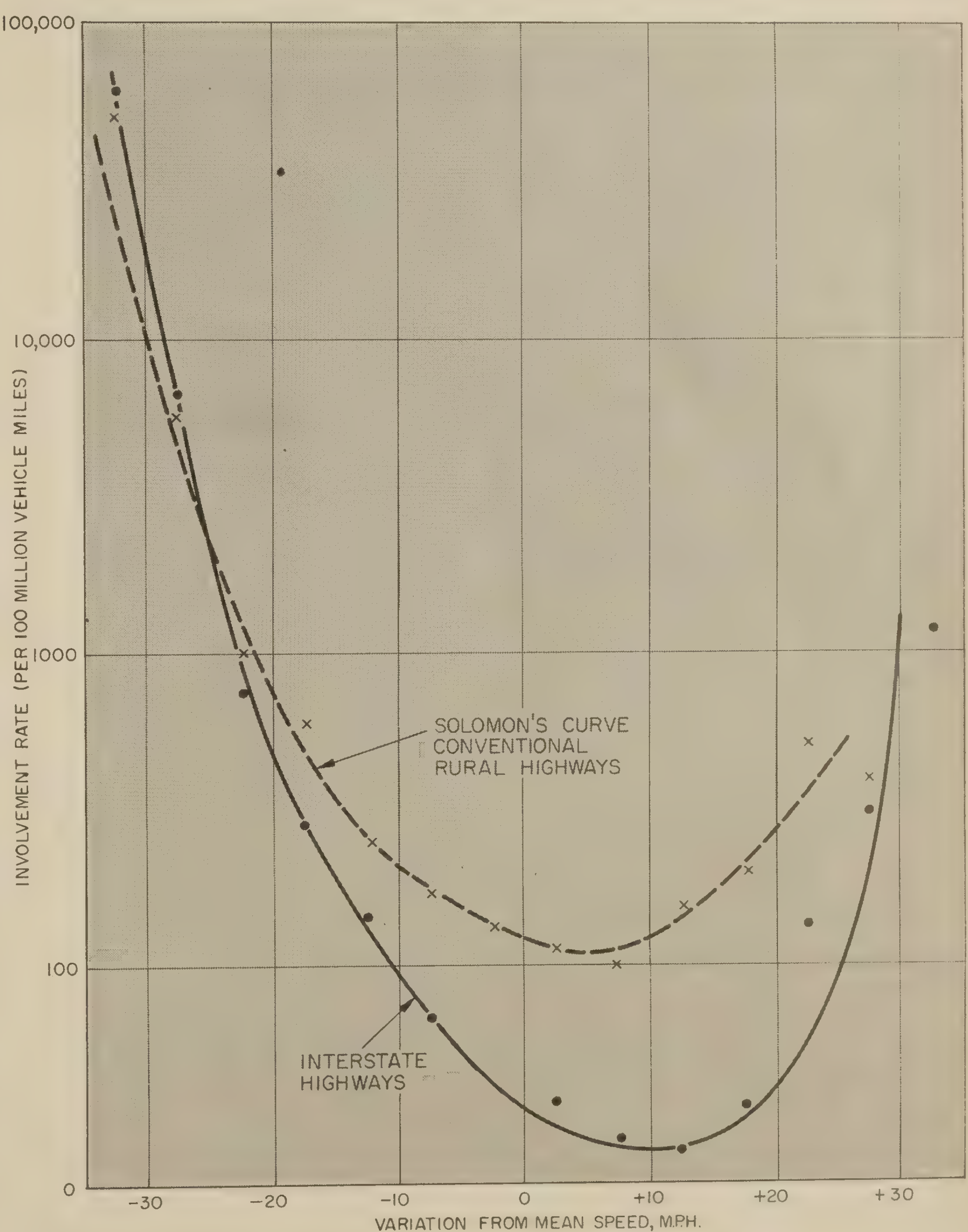

Figure 3.—Accident involvement rate by variation from mean speed on study units.

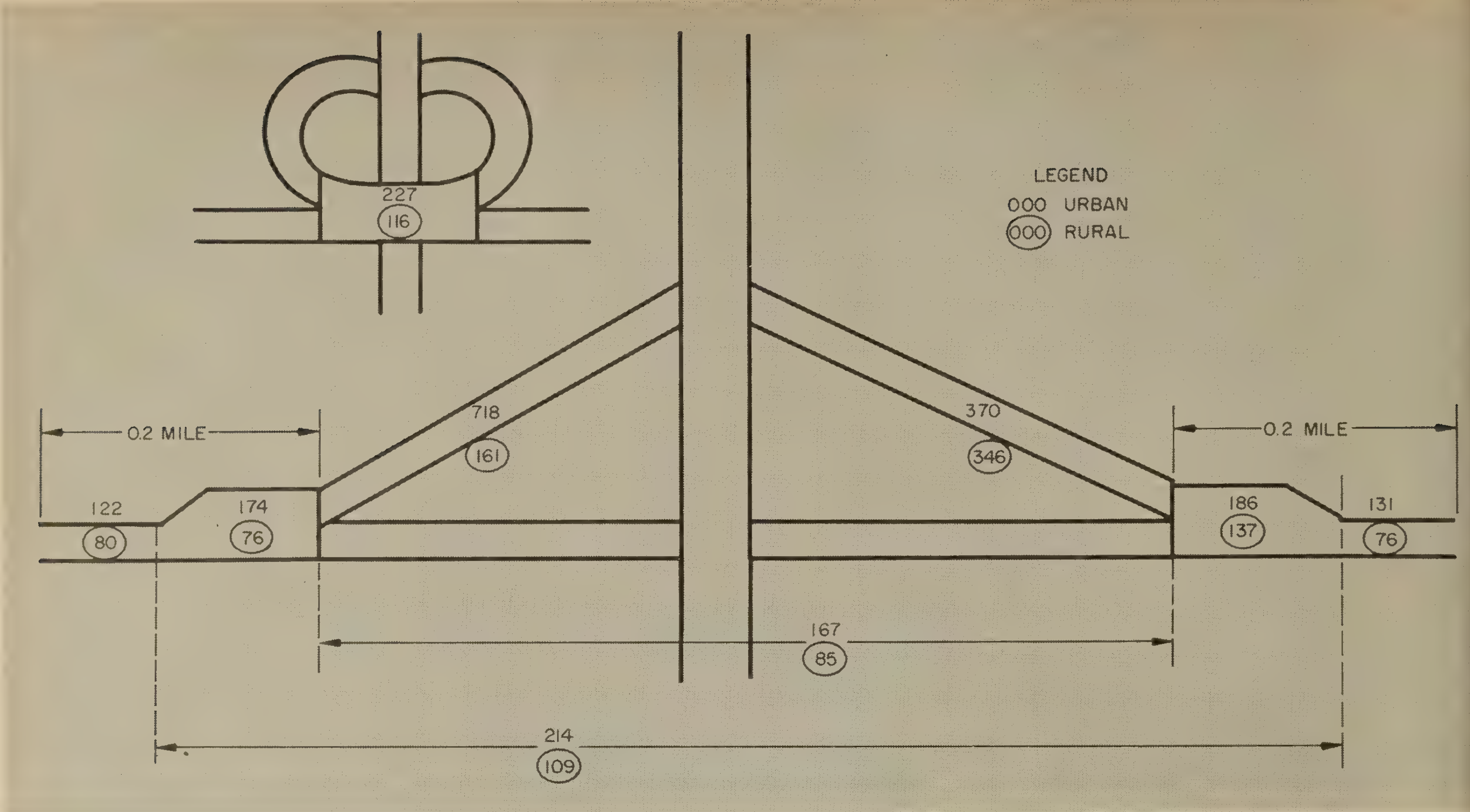

Figure 4.—Accident rate by type of interchange unit.

Distances were measured from the midpoint of each study unit to the gore (beginning of the ramp) and were recorded in discrete codes which represented continuous intervals of unequal length. The accident rates—the number of accidents per 100 million vehicle-miles—for both *between-interchange* units and *at-interchange* units were calculated. An interchange was assumed to extend from the beginning of the deceleration lane taper to the end of the acceleration lane taper. Thus, the following interchange units were included in this analysis:

- Deceleration lanes including taper
- Acceleration lanes including taper
- Exit ramps
- Entrance ramps
- Mainline units between speed-change lanes
- Combined acceleration-deceleration lanes

The *at-interchange* accident rate, shown on figure 4, was a weighted combination of the accident rates for each of these units. Accident rates were not calculated for crossroad units, terminal areas between ramps and crossroads, frontage roads, and local streets.

In interpreting the results of the analysis, it is essential to note that the only variables considered were the distances between the study unit and the interchange, and the classification of the section—rural or urban. No other variables were considered.

Table 2.—Involvement rate by type and level of enforcement

Type of enforcement	Level of enforcement per mile per year	Involvements: Cars	Involvements: Trucks	Mean speed	Vehicle miles: Cars	Vehicle miles: Trucks	Involvement rate[1]: Cars	Involvement rate[1]: Trucks
	Number	*Number*	*Number*	*m.p.h.*	*Millions*	*Millions*	*Number*	*Number*
Oral warnings	Less than 5	960	124	58.7	1,856	371	52	33
	5-14	140	59	58.3	287	71	49	82
	15-34	636	125	59.0	769	173	83	72
	35-74	537	103	59.8	632	124	85	83
	75-149	458	54	57.8	398	68	115	79
	150-299	308	39	58.3	354	49	87	80
	300-549	74	9	58.0	42	6	178	154
	600-1,199	14	2	57.8	7	2	195	108
	Over 1,200 [2]	------	------	------	------	------	------	------
	Unknown	211	22	57.2	407	77	52	28
Written warnings	Less than 5	848	167	57.5	1,361	28	62	60
	5-14	423	38	59.0	591	104	72	36
	15-34	717	101	60.4	805	179	89	56
	35-74	322	72	60.2	577	127	56	57
	75-149	399	94	60.3	701	141	57	67
	150-299	422	44	60.4	426	65	99	67
	300-549	101	10	57.4	144	25	70	40
	600-1,199	31	5	59.8	71	11	44	44
	Over 1,200 [2]	------	------	------	------	------	------	------
	Unknown	75	6	50.0	77	14	98	42
Car hours of police patrol.	Less than 5	13	0	57.9	13	4	96	00
	5-14	4	2	60.5	67	12	6	16
	15-34	68	7	55.9	204	43	33	16
	35-74	140	46	59.9	27	61	51	75
	75-149	337	74	58.2	568	142	59	52
	150-299	731	195	59.3	827	190	88	102
	300-549	296	41	59.5	774	168	38	24
	600-1,199	1,210	124	58.2	1,626	269	75	46
	Over 1,200	460	41	58.4	316	39	146	104
	Unknown	79	7	51.3	90	14	88	50
Arrests	Less than 5	130	12	57.5	323	661	40	18
	5-14	201	58	58.0	367	83	55	70
	15-34	501	117	59.2	832	182	60	64
	35-74	639	162	59.4	1,263	312	51	52
	75-149	876	101	58.7	1,082	170	81	59
	150-299	594	49	58.2	528	78	112	63
	300-549	292	24	58.7	198	27	148	90
	600-1,199	67	12	60.6	26	4	254	326
	Over 1,200 [2]	------	------	------	------	------	------	------
	Unknown	38	2	54.1	134	21	28	9

[1] Involvement rate = number of involvements per 100 million vehicle-miles.
[2] No data available.

Table 3.—Accident rate by proximity to interchange ahead or behind

Distance to exit-ramp nose ahead	Accidents	Accident rate [1]	Distance to entrance-ramp nose behind	Accidents	Accident rate [1]
EXIT SIDE			ENTRANCE SIDE		
URBAN			URBAN		
	Number	*Number*		*Number*	*Number*
Less than .2 miles	722	131	Less than .2 miles	426	122
.2– .4 miles	1,209	127	.2– .4 miles	1,156	125
.5– .9 miles	786	110	.5– .9 miles	655	105
1.0–1.9 miles	280	75	1.0–1.9 miles	278	84
2.0–3.9 miles	166	63	2.0–3.9 miles	151	59
4.0–7.9 miles	[2] 19	69	4.0–7.9 miles	200	75
More than 8 miles [3]	--------	--------	More than 8 miles [3]	--------	--------
RURAL			RURAL		
Less than .2 miles	160	76	Less than .2 miles	117	80
.2– .4 miles	459	75	.2– .4 miles	482	82
.5– .9 miles	559	69	.5– .9 miles	560	72
1.0–1.9 miles	479	69	1.0–1.9 miles	435	64
2.0–3.9 miles	222	68	2.0–3.9 miles	169	51
4.0–7.9 miles	46	62	4.0–7.9 miles	52	40
More than 8 miles [3]	--------	--------	More than 8 miles [3]	--------	--------

[1] Number of accidents per 100 vehicle-miles.
[2] Small sample size.
[3] No data available.

Results

The results reported below indicate that in rban areas, proximity of a study unit to an nterchange had a substantial effect on the ccident rate. A similar effect, of less magniude, was observed in rural areas for study nits near entrance ramps.

etween-interchange accident rates

As shown in table 3, the accident rate deeased on urban sections as the study unit as positioned farther away from an exit amp; the highest rate occurred in units less han 0.2 mile from the exit ramp. This derease was substantial to a distance of approxiately 2 miles from the ramp. Also, as a unit as stationed farther from the entrance ramp rea, the accident rate decreased, although ot uniformly. Moreover, the rates on both ides of the interchange were fairly comparale. On rural sections, however, the change in ates, as a unit was positioned closer to the nterchange, was not significantly altered; and n the exit direction it remained almost contant. Thus, in urban areas proximity to interhanges seemed clearly to affect the accident rate, probably because in urban areas interchanges occur almost twice as frequently as in rural areas (table 4), and usually carry much higher volumes.

Table 4.—Interchange-mileage relations by area type

Area type	Urban	Rural
Number of interchanges	718	942
Number of miles	1,380	3,919
Interchanges per mile	.52	.29
Miles between interchanges	1.9	3.4

At-interchange accident rates

Accident rates are presented, in figure 4, for each type of *at-interchange* unit; sample size is indicated in table 5. The total *at-interchange* accident rate was, as noted above, a weighted combination of the accident rates for each separate unit type computed for the 100 million vehicle-mile base.

When interpreting the figure, it is important to note that only exit ramps and entrance ramps are shown. Included in these calculations are ramps which are part of diamond-type interchanges, outer connections and loops of cloverleaf interchanges, semidirect and direct connections, and slip ramps.

The accident rate for urban interchanges is substantially higher than for rural interchanges, as these areas carry more traffic, making merging and diverging maneuvers more difficult. Because of higher right-of-way and construction costs, urban interchanges tend to be less standard in design, are more complex, and are confined to smaller areas than rural interchanges. These factors increase conflict possibilities, and also make entrance and exit maneuvers more difficult. The exceptionally high accident rate on entrance ramps in urban areas may be caused by inadequate acceleration lanes, or the lack of them, on many sections, necessitating vehicles to stop at the bottom of the ramp before moving into the traffic stream. Also, the unavailability of sufficient gaps in the main traffic stream makes it difficult to merge into moving traffic.

The accident rate on the mainline decreases after the deceleration lane has been passed (figure 4). It appears that after the decision point at the deceleration lane has been passed, the chances of an accident decrease.

From this brief analysis it can be determined that sections in proximity of interchanges experience a higher accident rate than other sections. Ramps have much higher accident rates than speed-change lanes (and paralleling main roadway) and these, in turn, have generally higher rates than the other portions of the main roadway.

Conclusion

The results reported demonstrate that on the Interstate System, as the speed of a vehicle varies from the mean speed of traffic, either above or below the mean speed, the chance of the vehicle being involved in an accident increases; that the level of enforcement has little or no apparent effect on the mean speed or on the accident experience of a study section; and that proximity to interchanges, especially in urban areas, appears to affect significantly the accident experience of the study section.

Although these results are not conclusive they provide some insight into areas in which more intensive research should be conducted, such as interchange spacing and utilization and more effective methods of speed control.

Table 5.—Accident rate by interchange unit and area type

Interchange unit	Rural: Vehicle-miles	Rural: Accidents	Rural: Accident rate [1]	Urban: Vehicle-miles	Urban: Accidents	Urban: Accident rate [1]
	100 Million	*Number*	*Number*	*100 Million*	*Number*	*Number*
Deceleration lane	2.51	348	137	5.83	1,089	186
Exit ramp	0.57	199	346	1.48	546	370
Area between speed change lanes	6.52	554	85	11.87	1,982	167
Entrance ramp	0.59	95	161	1.61	1,159	719
Acceleration lane	3.68	280	76	8.40	1,461	174
Acceleration-deceleration lane	0.49	87	116	2.45	555	227
Total	14.36	1,563	109	31.64	6,792	214

[1] Accident rate = number of accidents per 100 million vehicle-miles.

REFERENCES

(1) *Interstate System Accident Research—Study II—Interim Report I*, by Julie Anna Cirillo, Highway Research Record 188, Traffic Accident Research, 1967, pp. 1–7.

(2) *Accidents on Main Rural Highways Related to Speed, Driver and Vehicle*, by David Solomon, U.S. Government Printing Office, Washington, D.C., July 1964.

(3) *The Lone Driver Involved in Injury-Producing Accidents*, by William E. Schotz, Cornell Aeronautical Laboratory Inc., Cornell University, Buffalo, N.Y., Apr. 25, 1966.

(4) *Traffic Speed Trends*, U.S. Department of Commerce, Bureau of Public Roads, March 1965.

NEW PUBLICATION

Standard Plans for Highway Bridges, vol. II, Structural Steel Superstructures, 1968 ($1.00 a copy), is a revision of the 1962 edition with respect to bridge widths and current design specifications. These plans are intended to serve as a useful guide in the development of suitable and economical bridge designs. An effort has been made to give sufficient information on all plans so that they may be readily modified in the preparation of contract drawings.

The volume contains plans for simple span I-beam and welded girder superstructures from 20 feet to 180 feet, simple span two-girder with floor system superstructures from 120 feet to 200 feet, and continuous 3-span I-beam and welded girder superstructures with center spans from 50 feet to 240 feet. Bridge roadway widths used are 28 feet with H15-44 live load for low traffic volume low design speed roadways, 44 feet with HS20-44 live load for the standard 2-lane two-directional roadway and 40 feet with HS20-44 live load for the standard 2-lane one-directional roadway.

One series of simple span I-beam superstructures with Interstate loading and a variable width roadway is included in the plans.

Passing Aid System I, Initial Experiments

(*Continued from p. 70*)

ACKNOWLEDGMENTS

The cooperation of many persons of the Public Roads staff was necessary for the test driving and the collection and analysis of data for the experiments of Passing Aid System I. The persons assisting with the collection of field data included Raymond Greenwell, Santo Salvatore, Howard S. Ellis, and John Porter. The electronics system, designed by Raleigh Emery, was kept operational during driver test runs by Messrs. Novean and Porter. Margaret Cormack assisted with the scheduling of test subjects, the administrative details of ordering equipment, and the preparation of the final report. Statistical aid was supplied by Dr. Harry Weingarten and Mrs. Phyllis Mattison. Mr. David Solomon provided overall guidance and optimistic enthusiasm in conducting the analysis of Passing Aid System I.

REFERENCES

(*1*) *Introduction to Statistical Analysis*, by Wilfred J. Dixon and Frank J. Massey, Jr., McGraw Hill Book Co., Inc., First Edition, 1951, pp. 184 and 185.

(*2*) *Experimental Statistics*, by Mary Gibbons Natrella, U.S. Dept. of Commerce, National Bureau of Standards, 1963, p. T–3

PUBLICATIONS of the Bureau of Public Roads

A list of the more important articles in PUBLIC ROADS *and title sheets for volumes 24–34 are available upon request addressed to Bureau of Public Roads, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 20591.*

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.

Accidents on Main Rural Highways—Related to Speed, Driver, and Vehicle (1964). 35 cents.

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 (1966). 20 cents.

Annual Reports of the Bureau of Public Roads:

1963, 35 cents. 1964, 35 cents. 1965, 40 cents. 1966, 75 cents. 1966 supplement, 25 cents.

(Other years are now out of print.)

The Bridge to Your Success—Opportunities for Young Engineers in the Bureau of Public Roads (1967). 30 cents.

Calibrating and Testing a Gravity Model for Any Size Urban Area (1965). $1.00.

Capacity Analysis Techniques for Design of Signalized Intersections (Reprint of August and October 1967 issues of PUBLIC ROADS, a Journal of Highway Research). 45 cents.

Construction Safety Requirements, Federal Highway Projects (1966). 55 cents.

Construction Safety Requirements, Federal Highway Projects (1968). 50 cents.

Corrugated Metal Pipe Culverts (1966). 25 cents.

Creating, Organizing, & Reporting Highway Needs Studies (Highway Planning Technical Report No. 1) (1963). 15 cents.

Federal-Aid Highway Map (42 x 65 inches) (1965). $1.50.

Federal Laws, Regulations, and Other Material Relating to Highways (1965). $1.50.

Federal Role in Highway Safety, House Document No. 93, 86th Cong., 1st sess. (1959). 60 cents.

Freeways to Urban Development, A new concept for joint development (1966). 15 cents.

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

Highway Beautification Program. Senate Document No. 6, 90th Cong., 1st sess. (1967). 25 cents.

Highway Cost Allocation Study: Supplementary Report, House Document No. 124, 89th Cong., 1st sess. (1965). $1.00.

Highway Finance 1921–62 (a statistical review by the Office of Planning, Highway Statistics Division) (1964). 15 cents.

Highway Planning Map Manual (1963). $1.00.

Highway Planning Technical Reports—Creating, Organizing, and Reporting Highway Needs Studies (1964). 15 cents.

Highway Research and Development Studies, Using Federal-Aid Research and Planning Funds (1967). $1.00.

Highway Statistics (published annually since 1945):

1965, $1.00, 1966, $1.25.

(Other years out of print.)

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

Highway Transportation Criteria in Zoning Law *and* Police Power and Planning Controls for Arterial Streets (1960). 35 cents.

Highways to Beauty (1966). 20 cents.

Highways and Economic and Social Changes (1964). $1.25.

Hydraulic Engineering Circulars:

No. 5—Hydraulic Charts for the Selection of Higway Culverts (1965). 45 cents.

No. 10—Capacity Charts for the Hydraulic Design of Highway Culverts (1965). 65 cents.

No. 11—Use of Riprap for Bank Protection (1967). 40 cents.

Hydraulic Design Series:

No. 2—Peak Rates of Runoff From Small Watersheds (1961). 30 cents.

No. 3—Design Charts for Open-Channel Flow (1961). 70 cents.

No. 4—Design of Roadside Drainage Channels (1965). 40 cents.

Identification of Rock Types (revised edition, 1960). 20 cents.

Request from Bureau of Public Roads. Appendix, 70 cents.

The 1965 Interstate System Cost Estimate, House Document No. 42, 89th Cong., 1st sess. (1965). 20 cents.

Interstate System Route Log and Finder List (1963). 10 cents.

Labor Compliance Manual for Direct Federal and Federal-Aid Construction, 2d ed. (1965). $1.75.

Amendment No. 1 to above (1966), $1.00.

Landslide Investigations (1961). 30 cents.

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

Manual on Uniform Traffic Control Devices for Streets and Highways (1961). $2.00.

Part V only of above—Traffic Controls for Highway Construction and Maintenance Operations (1961). 25 cents.

Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-Aid Systems, House Document No. 354, 88th Cong. 2d sess. (1964). 45 cents.

Modal Split—Documentation of Nine Methods for Estimating Transit Usage (1966). 70 cents.

National Driver Register. A State Driver Records Exchange Service (1965). 20 cents.

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

Presplitting, A Controlled Blasting Technique for Rock Cuts (1966). 30 cents.

Proposed Program for Scenic Roads & Parkways (prepared for the President's Council on Recreation and Natural Beauty), 1966. $2.75.

Reinforced Concrete Bridge Members—Ultimate Design (1966). 35 cents.

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

Road-User and Property Taxes on Selected Motor Vehicles (1964). 45 cents.

Role of Economic Studies in Urban Transportation Planning (1965). 45 cents.

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

Standard Land Use Coding Manual (1965). 50 cents.

Standard Plans for Highway Bridges:

Vol. II—Structural Steel Superstructures (1968). $1.00.

Vol. IV—Typical Continuous Bridges (1962). $1.00.

Vol. V—Typical Pedestrian Bridges (1962). $1.75.

Standard Traffic Control Signs Chart (as defined in the Manual on Uniform Traffic Control Devices for Streets and Highways) 22 x 34, 20 cents—100 for $15.00. 11 x 17, 10 cents—100 for $5.00.

Traffic Assignment Manual (1964). $1.50.

(1963). 15 cents.

Traffic Safety Services, Directory of National Organizations

Transition Curves for Highways (1940). $1.75.

Typical Plans for Retaining Walls (1967). 45 cents.

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

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U.S. GOVERNMENT PRINTING OFFICE

If you do not desire to continue to receive this publication, please CHECK HERE ☐; tear off this label and return it to the above address. Your name will then be removed promptly from the appropriate mailing list.