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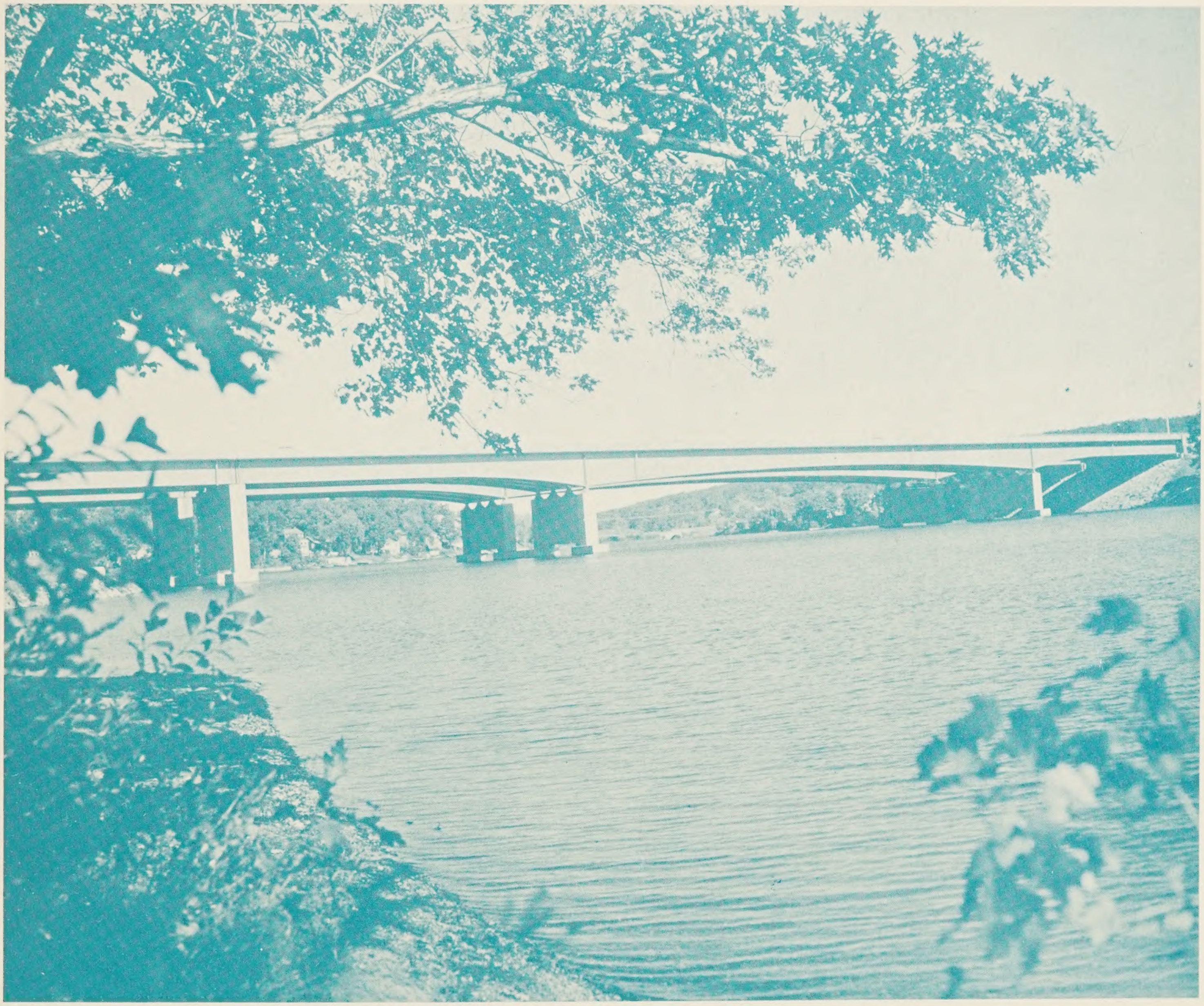
Public Roads

A JOURNAL OF HIGHWAY RESEARCH



U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

Public Roads

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I–290 bridge crossing Lake Quinsigamond, Worcester–Shrewsbury, Mass. (Photo courtesy of Massachusetts Department of Public Works.)

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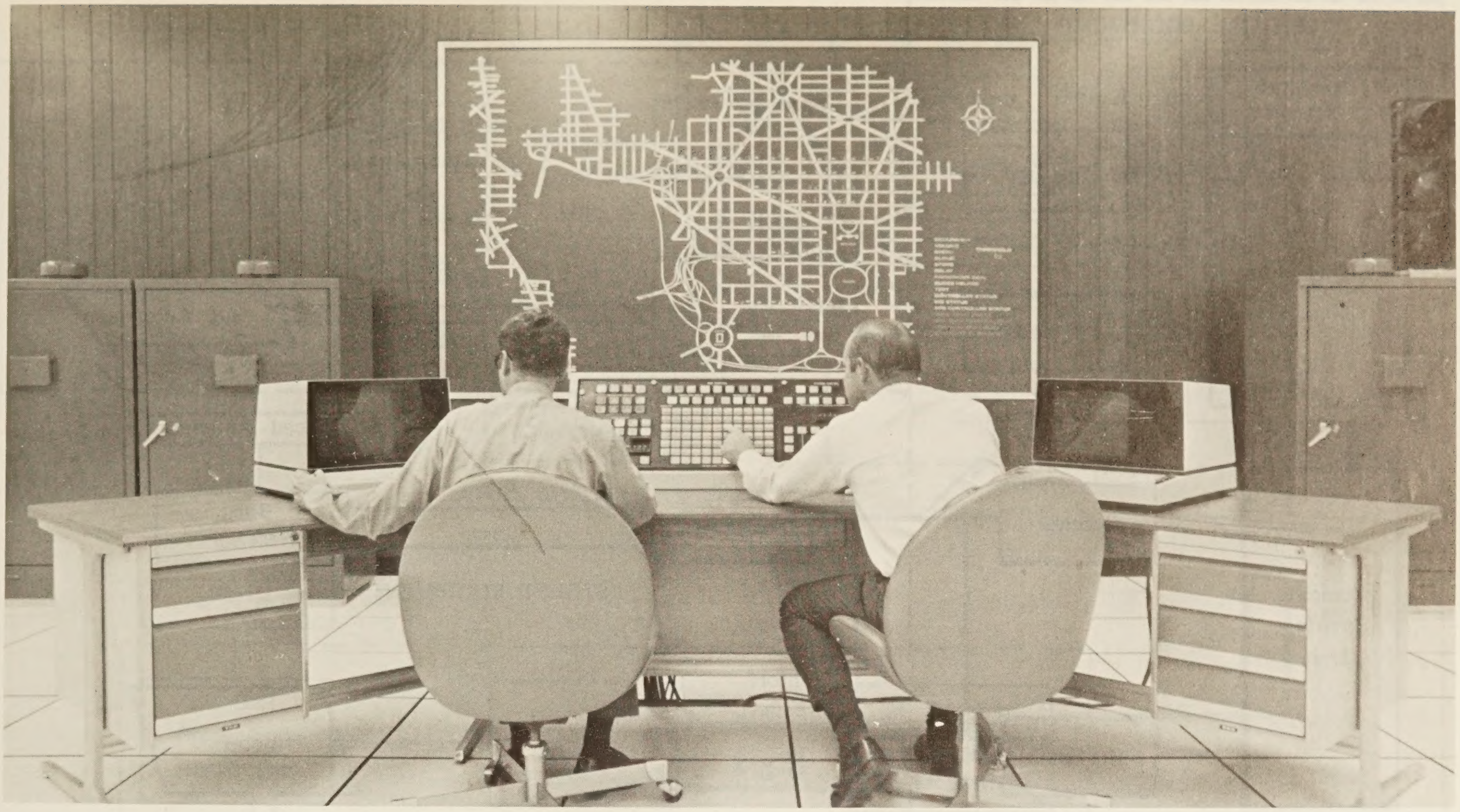


UTCS/BPS Traffic Control Center.

Traffic Surveillance and Control in an Urban Test Facility

Reported by FRANK J. MAMMANO,
Electronic Engineer,
Traffic Systems Division

OFFICE OF RESEARCH

Introduction

THE URBAN Traffic Control System/Bus Priority System (UTCS/BPS) is a digital computer controlled traffic signal system currently being installed in Washington, D.C. Sponsored by the U.S. Department of Transportation, the system is serving as a street test facility for new and advanced traffic control techniques.

Field components of the system are as follows: (1) A surveillance system consisting of 521 inductive loop detectors and 144 bus detectors, (2) intersection controllers for 112 signalized intersections, and (3) a detector and controller communication system between the control center and the surveillance system. Figure 1 is a block diagram of the entire system. This article concentrates on the field hardware of the system, describes their operation and construction, and includes a detailed explanation of the vehicle detector installation.

Intersection Controllers and Communication System

UTCS/BPS uses three dial fixed time controllers equipped for operation in a wire and/or a radio interconnected system. The computer times all controller timing intervals and activates the controller by advancing the camshaft. Criteria for selecting these types of controllers were compatibility with existing signal system, reliability, and low cost. In the standby mode, the three dials are used for three specific time-of-day timing patterns: morning peak, evening peak, and off peak. The controller, therefore, remains intact and provides a backup (standby mode) for the computer-controlled system. Few semiactuated controllers are in the system.

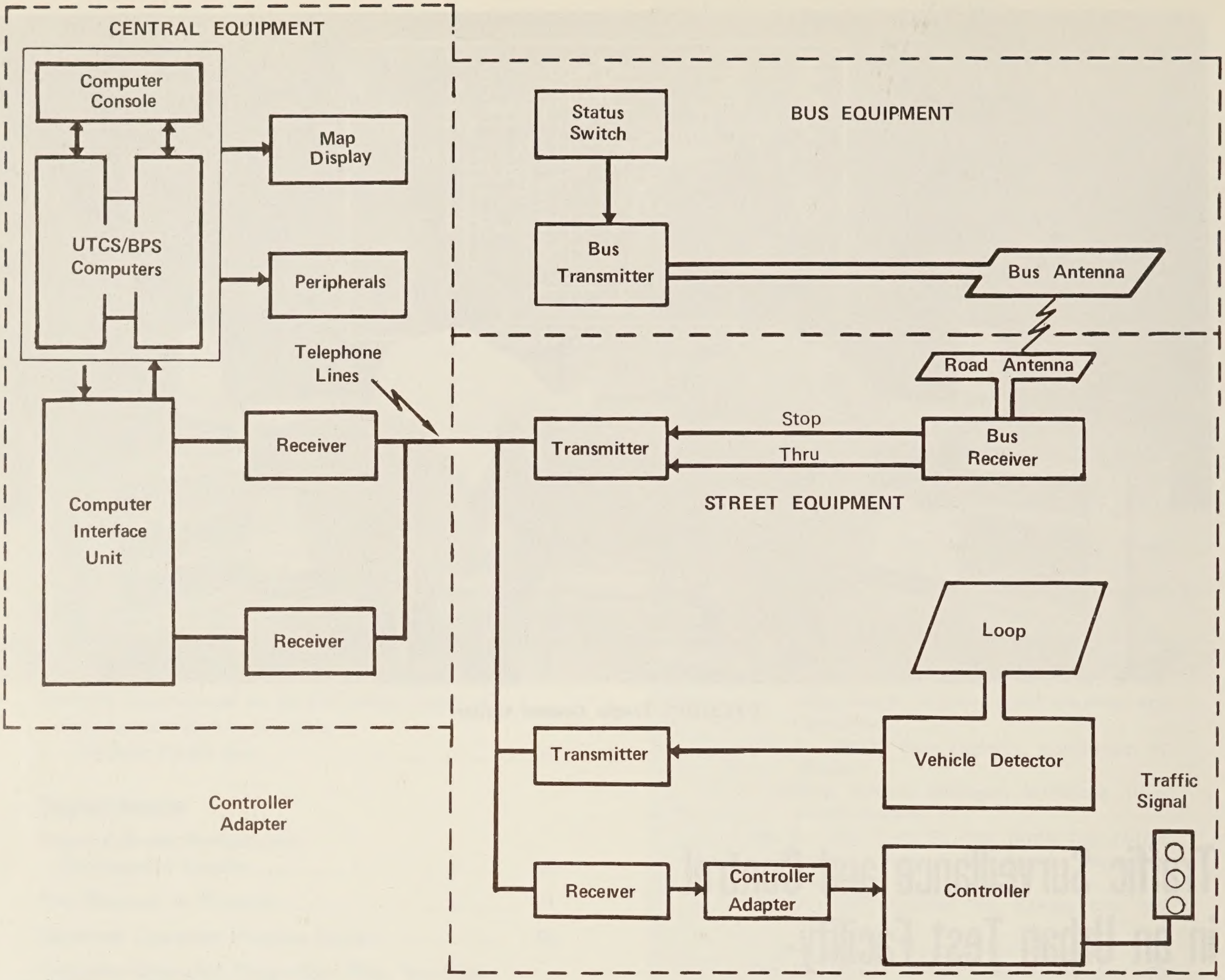


Figure 1.—System block diagram.

Those in the system, however, are also under computer control.

Adapter units added to the controllers convert the advance and hold signals from the communication receivers to a form suitable for driving the controller circuits. They also convert the "A" phase green return signal to a form acceptable to the communications transmitter.

Communication between the intersection and the central computer is performed by frequency division multiplexing (FDM) over leased telephone lines. This technique was selected based on cost and comparison with the operational characteristics of various techniques, such as time division multiplexing, direct wired, polarized d.c., and amplitude modulated FDM. The telephone lines have a maximum capacity of 20 channels per line. Two frequency shift keying (FSK) is used to transmit the vehicle detector pulses and the "A" phase green return one way from the intersection to the control center. Carrier frequency is monitored to determine detector malfunction. Three frequency shift keying (3 FSK) is used to transmit the status of the bus detectors and the advance and hold pulses for the traffic signal controllers (fig. 2).

Surveillance System

Vehicle detectors

Local ordinance and technical considerations were the basis for selecting the inductive loop detector. The loop detector consists of three turns of wire embedded in the roadway pavement. This wire is connected to the detector electronics located in a cabinet at the intersection.

The detector is designed so that the passage of a vehicle over the loop in the pavement modifies the magnetic flux around the resonantly tuned loops of wire, thereby increasing or decreasing the inductance so that a change in phase shift is detected by the electronics. This change is then transmitted to an amplifying or relay circuit.

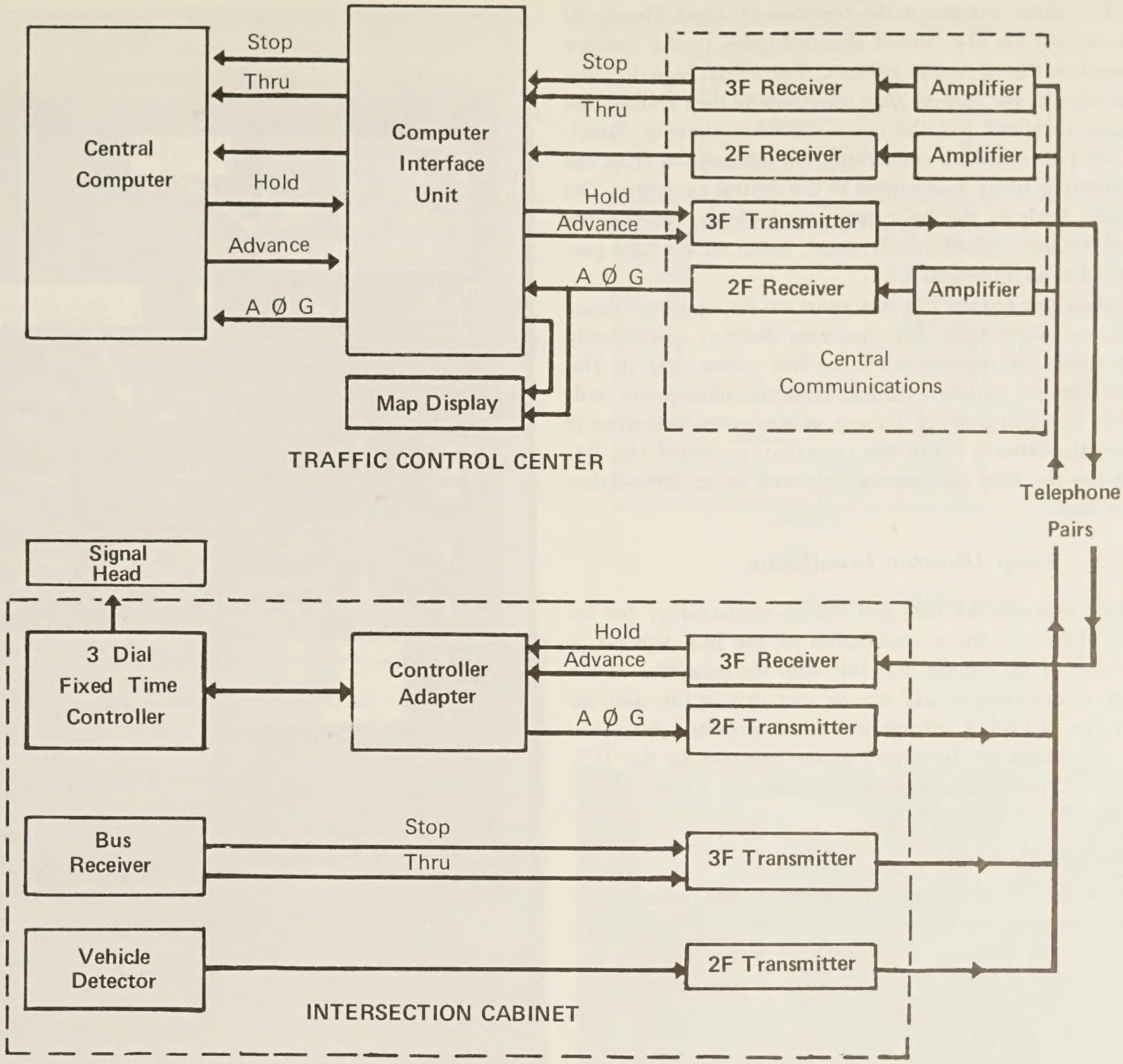


Figure 2.—Controller tie-in

The loop detector can be used either as a presence or pulse sensor. When a vehicle stops and remains in the detection zone, however, the detection of the vehicle's presence is terminated after a period of time and other vehicles passing within the detection zone will be sensed. Departure of a stopped vehicle from a loop does not produce another detection count. The holding time depends on the magnitude of electronic detection voltage, which in turn is related to the loop size, transmission line length, the vehicle type, and its position in the loop. In the UTCS system the loop detector output is used to compute speed, occupancy, volume, and queue length.

Bus detector

Several techniques were investigated and tested for use in the bus priority system. It was decided that near field radio would be the most reliable since the required close coupling between loops limits the coverage to the dimensions of the receiving loop. Also the limited range reduces false alarm probability.

The system allows preferential treatment to buses by extending the green phase of a traffic signal. A bus-mounted transmitter, antenna, and status (*stop* or *thru*) switch, loop antennas buried in the pavement, and receivers housed in the controller cabinet are included in the system. The bus detector equipment requires a communication system and a traffic controller along with a central computer. A status switch mounted on the steering column of a bus has two positions operated by the driver to indicate whether he will be stopping at the intersection for passengers or going through. A loop antenna, mounted on the underside of the bus close to the rear, is an integral part of the transmitter. A continuous signal is produced at 168 kHz to indicate a *stop* or 182 kHz to indicate a *thru*.

The roadway antenna consists of a single turn of wire separated by 1 inch insulating material embedded vertically in the pavement and extending transversely across all approach lanes of traffic at an intersection. A magnetic field produced by the transmitter loop couples the signal to the buried loop antenna when the transmitter is within 1 foot of the antenna in the direction of travel. The signal is then transmitted via the twisted shielded cable to the detector receiver based in the controller cabinet. The output signal of the detector receiver at the *stop* or *thru* terminals is then transmitted to the central computer via the communication channel. Simultaneously, other information concerning the intersection from the vehicle detectors is being transmitted to the central computer. The computer then analyzes the information and decides whether an extension of the green phase is warranted, based on the total passenger demand at an intersection.

Two antennas are buried 175 feet apart on the approach lanes of traffic at an intersection. The upstream detector immediately gathers the status information when the bus passes over it. The downstream detector, which is 35 feet from the intersection, will count out the bus and prevent a waste of the green extension if the bus clears the detector before the extension is granted (fig. 3). Figure 4 shows the field components mounted in an intersection controller cabinet.

Loop Detector Installation

This section explains the field installation methodology for inductive loop detectors. Since installation of the bus detector is identical to that of the vehicle detector, with the exception of the loop saw cut dimensions, it will not be included in this section. Portions of the following information were obtained from the installation specifications developed under contract to the U.S. Department of Transportation for the installation of the Urban Traffic Control/Bus Priority Project.

Preliminary preparations

The preliminary preparations for making loop installations should include a scale drawing of the roadway showing the location

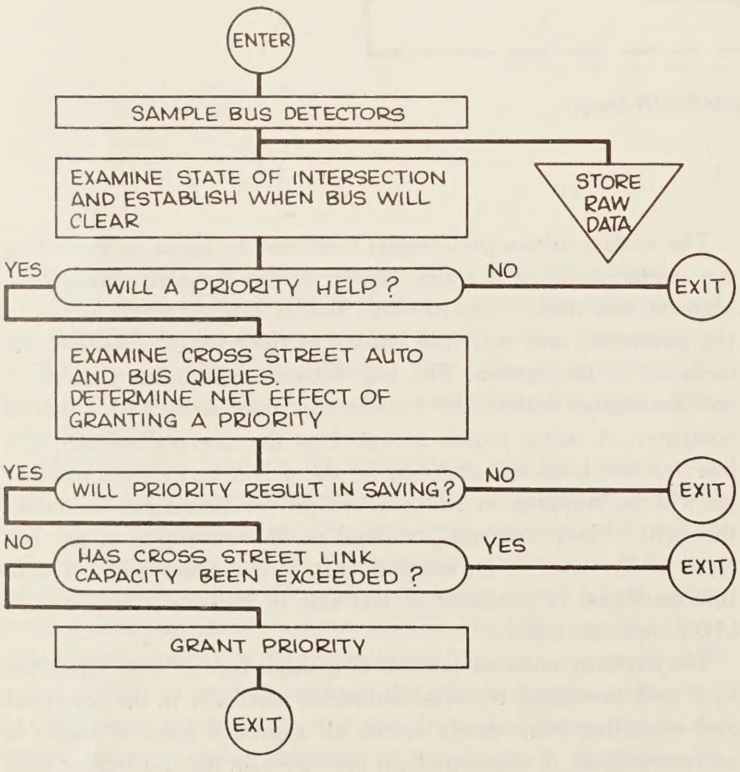


Figure 3.—Simplified flow chart BPS intersection control.

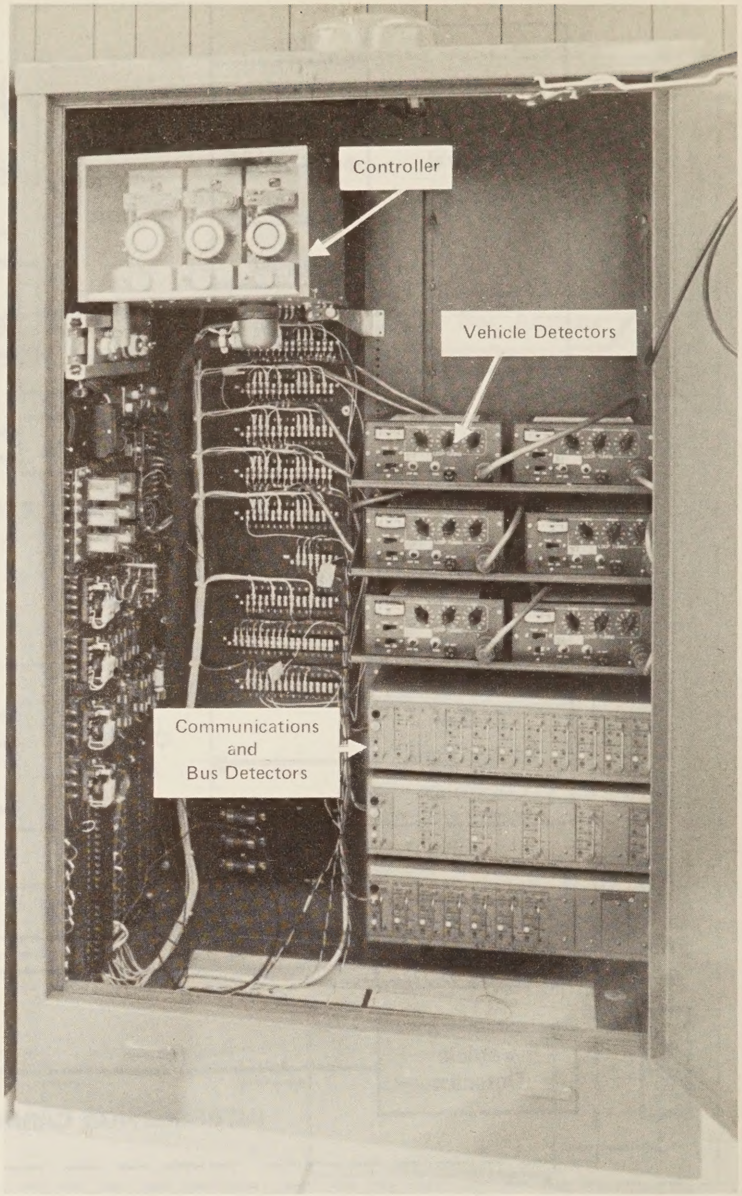


Figure 4.—Intersection controller cabinet.

and content of conduit, manholes, power sources, pavement materials, and electrical equipment that may be involved or may interfere with the loop installation. These plans should show the exact size and the materials involved for each loop to be installed.

An onsite inspection should be made of each location before and after the loop installation drawings are prepared. This onsite inspection is needed to make the following determinations:

- Exact location and number of loops.
- Exact size of each loop.
- Type of equipment needed for the particular installation.
- Exact location of power manholes.
- Exact location of communication source.
- Nearest source of water for cooling the saw.
- Required electrical tie-ins.
- Location of the roadside equipment cabinet.
- Strategy for burying feeder cables, by sawing, trenching, rodding, tapping.
- Position and quantity of barricades according to the specifications in the jurisdictions.

● Methods for routing traffic around the location during installation.

● Best period of the day or night for making actual installation.

Checks must be made to insure that the proper permits, licenses, and insurance (requirements vary for each jurisdiction) are obtained by the responsible agency before installation.

Specific preparations must be made regarding the programing of personnel and equipment required for installing loops. The following equipment determinations and acquisitions must be made:

● Required flagmen, barricades, signs, and cones to conform to the specifications of the jurisdictions where the installations will occur.

● Adjustable template or straight edge for drawing an outline of loops on the pavement (fig. 5).

● A self-propelled powersaw with diamond blade or abrasive saw blades for sawing pavements to the length, depth, and width shown in figure 6. The powersaw should be equipped with a depth measurement device, water valve, and guide.

● Splice boxes for connecting loop lead-in to feeder cable (fig. 7).

● If needed, a drill for boring 1-inch hole through curb for conduit to hold lead-in wire to splice box (fig. 8).

● Water supply (hydrant or water truck) to keep diamond blade cool and to clean slots.

● Air compressor for cleaning out the sawed slots.

● Small trenching machine for burying cable in dirt.

● Equipment for tapping holes in manholes.

● Equipment for rodding cable in conduit.

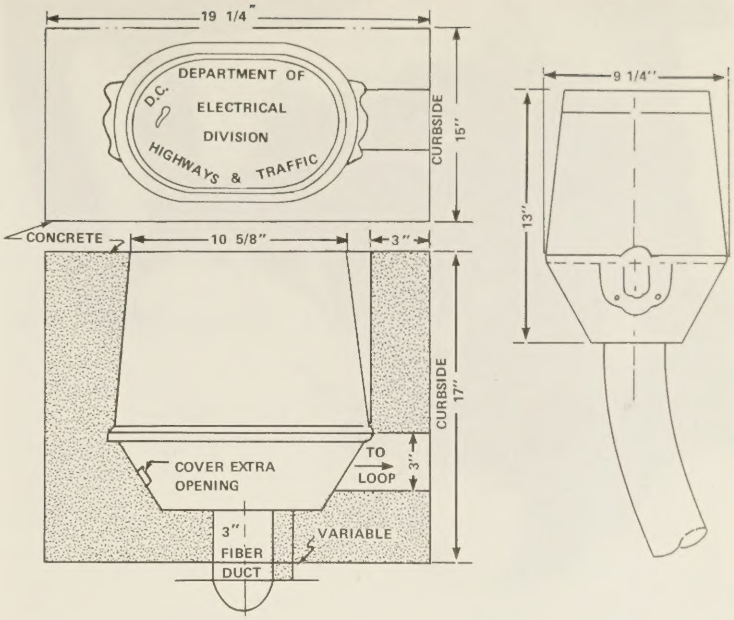


Figure 7.—Splice box.

Figure 5.—Template for layout of loop detector.

Figure 8.—Drill for boring hole through curb.

Figure 6.—Self-propelled saw cutting loop slot.

Figure 9.—Placing sealer in slot.

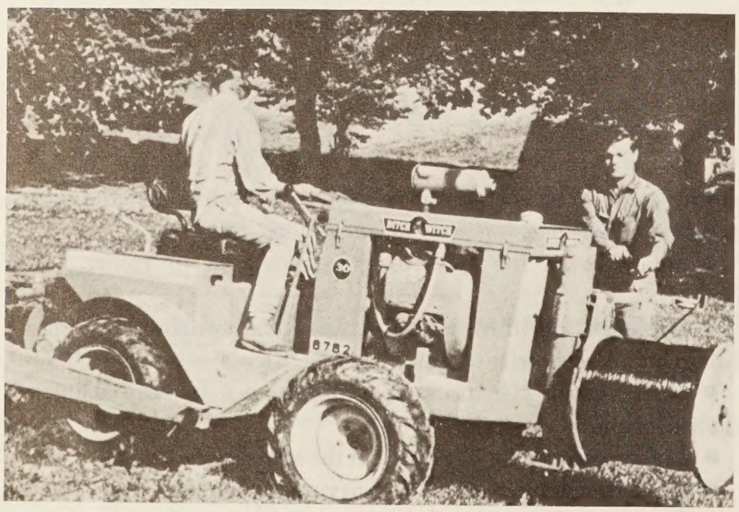


Figure 10.—Equipment for burying feeder cable in soil.

- A flexible embedding sealer for the saw cut (fig. 9).
- Concrete for setting splice box in place.
- Utility construction equipment for burying cable for long lead distances in the shoulder of the roadway (fig. 10).
- A 110-volt gasoline generator or other power source for making solder connections, splicing, and to furnish auxiliary lighting for night work.
- All-weather electrical tape and adhesive coating for splicing feeder cable and lead-in wire in splice box (fig. 11).
- Loop wire, XHHW No. 14 AWG stranded, single conductor (cross-linked polyethylene insulated wire), feeder cable—suitable twisted shielded cable.
- Megger meter for checking integrity of loop insulation (fig. 12).
- Loop tester for checking continuity and inductance of loop (fig. 13).

Manpower requirements for making loop installations must be made. The following is an itemized listing of the time and labor required for a typical loop installation:

Crew	*Work performed*	*Time*
3 laborers	Set up traffic control	20 minutes.
Do	Lay out road cut for loop	5 minutes.
Do	Cut slot for 6- by 6-ft. loop with 20 ft. lead including setup and teardown time.	1 hour, 5 minutes.
Do	Clean slots	5 minutes.
Do	Install loop wire in slot and clean up	20 minutes.
Do	Dig hole for splice box and drill curb for conduit, install splice box, backfill, concrete, and finish.	2 hours, 30 minutes.

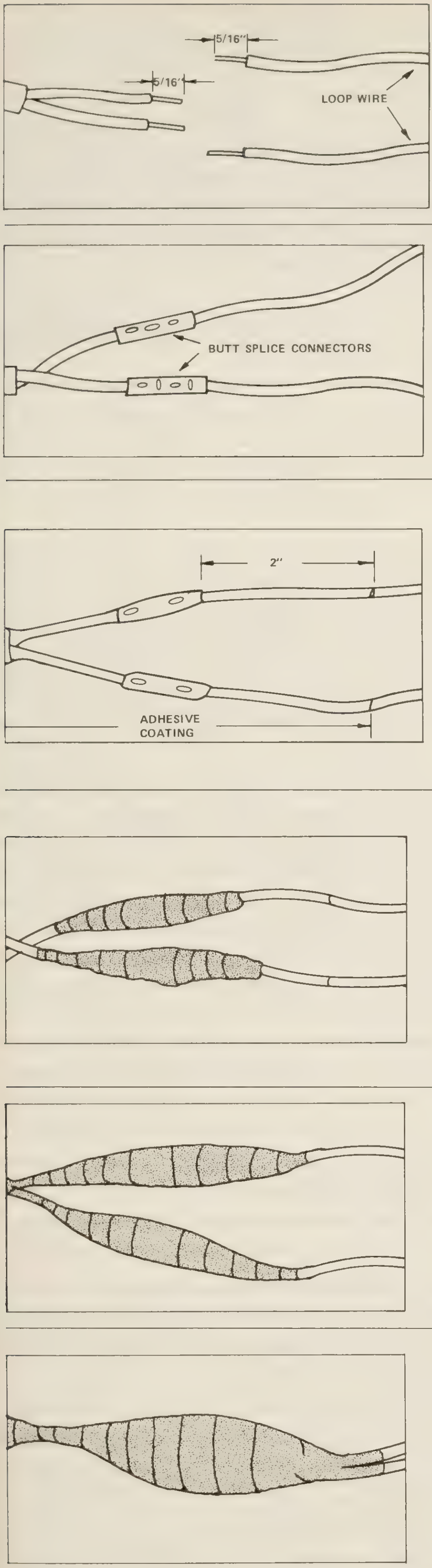
Many of the tasks just mentioned can be performed simultaneously, thus reducing the amount of manpower and time. Also, this is assuming that only one loop is being installed. If there were more than one loop in the same area, there would be an overall reduction in manpower and time.

Installing the loop

General.—Proper installation of the loop is of the utmost importance. The wires, being underground, are subject to deterioration from chemicals in the soil, water, rodents, and damage from shifting of pavement, frost, and improper installation procedures.

Interruption of the normal flow of traffic should be held to the minimum time necessary for installation of the road loop. To accomplish this a checklist should be completed and work should not begin until all material, equipment, and personnel are at the site. Barricades, warning signs, and flagmen must be deployed to protect the workers and the traveling public.

Planning.—This task involves the review and familiarization of drawings, installation procedures, and materials to be used in advance of actual installation. Planning and scheduling daily operations should be accomplished well in advance of the actual installation to insure material availability, agency notification, and manpower loading. Any detector installations at the same location should be performed concurrently.



Step 1

Strip wires as shown. Allow bare wire to extend approximately 5/16 inch.

Step 2

Make splices using insulated pressure type wire connectors.

Step 3

Brush on a single coat of waterproof adhesive. Coat to cover ½ inch of twisted shielded cable outer jacket, exposed cable inner jackets, wire connector, and 2 inches of loop wire insulation. Allow adhesive coating to dry (at least 5 minutes).

Step 4

Wrap each splice with ¾-inch self-bonding electrical tape or equivalent. Half lap starting at center of splice and proceeding approximately ¾ inch past connector end, back over connector to ¾ inch on other end and returning to center.

Step 5

Wrap each splice with ¾ inch all-weather electrical tape. Follow same procedure as in step 4. Cover previous layer of tape.

Step 6

Wrap both splices together with ¾-inch all-weather electrical tape. Cover entire splice area including adhesive coating applied by step 3. Complete splice by inserting a 4-inch piece of tape into the V forming by the loop wire.

Figure 11.—Procedure for splicing feeder cable and lead-in.

Figure 12.—Use of Megger meter.

Figure 13.—Use of loop tester.

Layout.—Installation begins with marking the layout of each loop on the pavement. Care should be exercised to place the loop at the designed location, perpendicular to the roadway lane and it should be the proper size to insure the detection of all vehicles using the lane. The layout can be facilitated by using a template of the proper size and shape and marking the pavement with lumber crayon or spray paint to guide the saw. The loop should conform to the dimension required with overlap cuts as shown in figure 14.

The loop to splice box lead-in dimensions will vary with each site; however, figures 15 and 16 show an example of how they can be run.

Curb entry if required.—This task refers to the coupling of the splice box to the lead-in saw cut (fig. 15).

The chase from the saw cut to the splice box should extend no greater than 1 foot from the curb. It should be made by a punch or drill type tool rather than by the usual excavating methods.

Conduit should be used from the splice box to its intercept with the saw cut. The visible portion of the curbing should not be cut for conduit installation.

Conduit should be installed so that it receives directly the lead-in wire in line and not at an angle. The hole to receive the conduit should be sufficiently below the roadway surface so that there is a minimum of 2 inches of cover on top of the conduit when installed. The top 2 inches of cover over the conduit hole should be of the same sealant used to close the saw cut. The conduit installation should be accomplished at the same time as the splice box installation.

Saw cut.—To saw slots in the pavement use a self-propelled powersaw equipped with a diamond blade or abrasive blade; the diamond blade is much faster and lasts longer. Both types of blades require a constant water supply, which is used as a lubricant and coolant for the blade. The saw must be equipped with a depth gage and horizontal guide to assure the proper depth and alinement of the slot. Care should be exercised during marking and sawing of slots to avoid alinement deviations that require resawing. The extra slot may weaken the pavement and cause a failure.

Diamond blades used for the saw cut should provide a clean, well defined $\frac{5}{16}$-inch-wide cut without damage to adjacent areas. The cut depth is a minimum of $1\frac{3}{4}$ inches not to exceed 2 inches (fig. 16). Saw cuts are overlapped to provide full depth at all corners. All slots requiring a right-angle turn of wire are cut at a diagonal to prevent sharp wire bends (fig. 14). Slots may be cut ahead of wiring and wood strips inserted in the slot or a protective panel over the slot to prevent shrinkage or damage (fig. 17).

Cleaning of saw cut.—Prior to the installation of wire, saw cuts should be checked for jagged edges or protrusions, cleaned, and dried. There should be no cutting dust, grit, oil, moisture, or other contamination in the saw cut.

Slots should be flushed clean by water, then dried by blown air. The blown air, from the compressors, should be free of oil or water. Slots should be cleaned immediately after the cutting operation (fig. 18). Care should be taken during cleaning to avoid blowing the debris at passing pedestrians and motorists.

Wire installation.—Before proceeding with the wire installation, it is imperative that the slot be cleaned and free of water. All wire installation must be made without damage to the wire or its insulation, and all damaged wires must be replaced. Wire should be

Figure 14a.—6 by 6 foot loop cut showing markings on pavement.

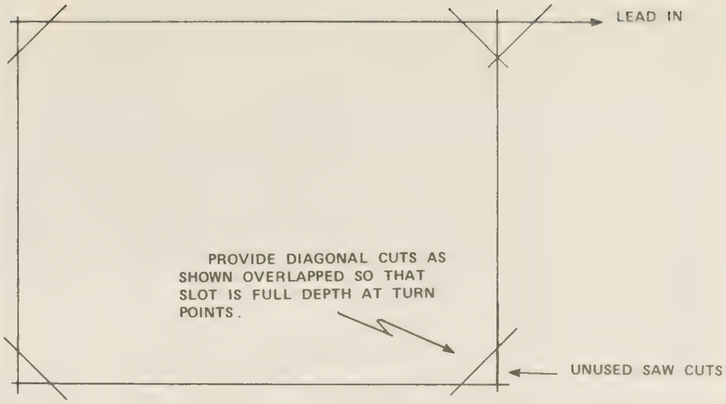


Figure 14b.—Vehicle loop slot construction.

Figure 14.—Typical loop layout.

type XHHW, No. 14 AWG, stranded, single conductor (cross-linked polyethylene insulated wire). Loops are installed as per figures 14, 15, and 16 and shall contain three complete turns.

The wire is laid in the slot so that there are no kinks or curls and no straining or stretching of the insulation. It should be installed as deep in the slot as possible. A blunt object, similar to a wooden paint stirrer, is used to seat the loop wire. A screwdriver or other sharp tool should not be used for this purpose.

The loop lead-in wires are twisted to provide a minimum of one turn per foot from the loop to the splice box. A minimum of 3 feet of lead-in pair slack should be coiled and left in the splice box.

The wire should be held in place during installation by short strips of a polyethylene foam sealant backer. The hold-down strips should be about 2 inches long and placed approximately every 2 feet. These strips should be left in the slots during pouring of the sealant. Where the loop wire crosses cracks or joints in the pavement, plastic sleeving should be used to insulate the wire. The sleeve should extend a minimum of 4 inches on each side of the joint.

Splice box installation.—The splice box should be installed at locations shown in the installation drawings. Figure 7 shows a type of splice box that can be used. Installation should be similar to the following procedure:

- Excavate, at the proper location, to house the splice box.
- Provide support for the splice box (no forms to be used) with its cover flush with the ground (see fig. 19).
- Install a short section of conduit from splice box to pass under curbing (if any) and pick up detector lead-in saw cut and chase (fig. 15).
- Install a bend from splice box in the direction of manhole, or conduit, as shown on installation drawings (fig. 20).
- Pour concrete around splice box (fig. 21).
- Backfill finish (fig. 22).

Testing.—Prior to pouring the sealer, the loop and lead-in should be checked for continuity and resistance. In addition, the integrity of the insulation is checked by applying a megger between each end of the loop lead-in and the nearest reliable electrical ground—street light, fire hydrant, etc. If no available ground exists, a suitable ground is established for the measurement (driven metal spike). The megger reading should be in excess of 10 megohms

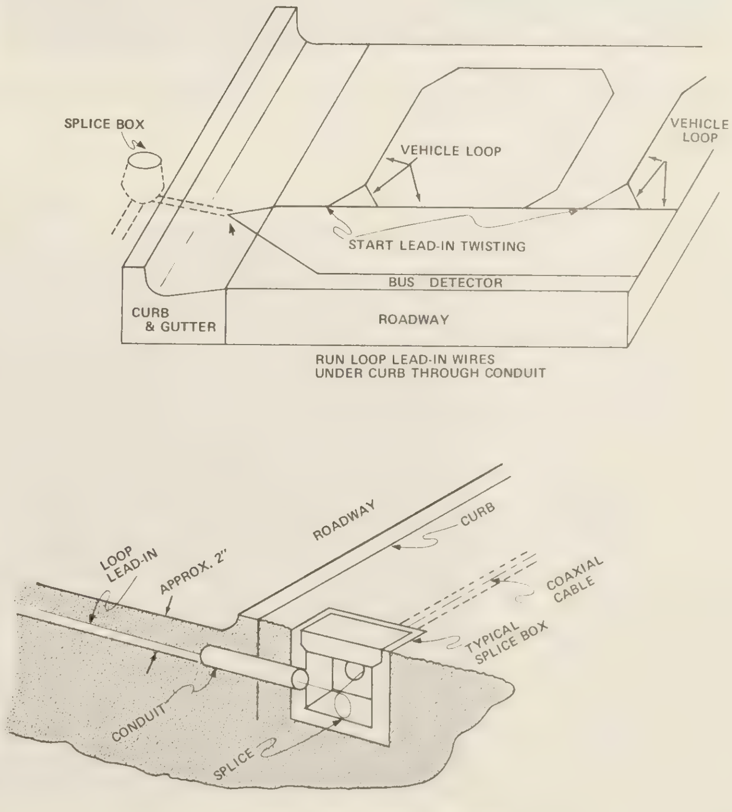


Figure 15.—Loop lead-in.

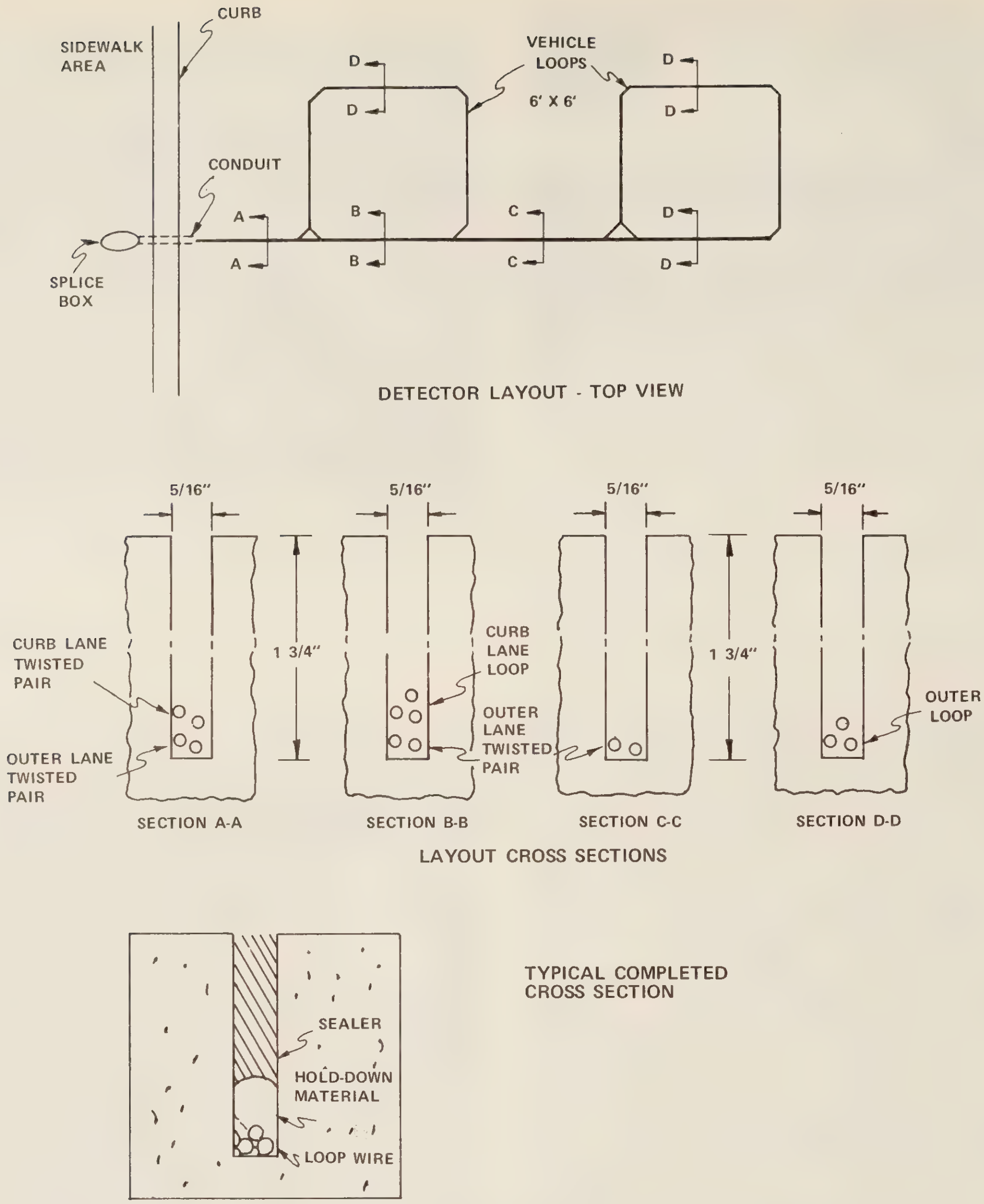


Figure 16.—Detector layout and cross section.

under any conditions (see figs. 12 and 13.) Then record the location, megger readings, and the indication of satisfactory compliance with the continuity check.

Saw cut seal.—Flexible embedding sealer should be used strictly in accordance with the manufacturer's instructions. It should be poured into the slot to half depth. When both the loop and lead-in slots are half filled, check for air bubbles or material pile up and then proceed to fill the slots to roadway level. Excess sealant should be removed by a *squeegee.* In any case, a trough or a mound should not be formed (see fig. 9).

The sealer, when poured into a saw cut, should completely surround the wires, displace all air therein, and completely fill the area of the slot, except for that portion filled with the wire hold-down material. Allow sufficient time for the sealer to harden in accordance with manufacturer's instructions (minimum of 1½ hours) before allowing traffic to move over the area.

Final test.—Repeat the entire test as specified in "Testing" section.

Detector feeder cable installation.—(1) In areas where there are sidewalks, the feeder cable and the loop lead-in wire should be terminated in a splice box and a waterproof splice made at that point with whatever cable is recommended (fig. 11). The cable is then placed in the conduit from the handhole to the control box or to a manhole.

(2) In soil, the coaxial cable is placed a minimum of 18 inches deep by open trench method. The cable is surrounded with sand (meeting the requirements for concrete) to a depth of 4 inches on all sides. The trench is then backfilled in layers not to exceed 6 inches loose and compact with mechanical tampers to the approximate density of the original ground (density will vary). The loop lead-in wire and feeder cable can be terminated in a splice box. The coaxial cable may be placed by direct burial method (fig. 10)

Figure 17.—Protective plates over sawed slots.

Figure 18.—Cleaning out sawed slots.

Figure 19.—Support to maintain splice box level and flush with sidewalk.

Figure 20.—Installation of bend from splice box in the direction of the manhole.

Figure 21.—Concrete around splice box.

Figure 22.—Finished installation of splice box.

provided it can be demonstrated that the method of installation will not damage the cable.

(3) In areas where the roadway ends and the shoulder begins, a slot is cut at a down angle of approximately 30° to avoid shearing the lead-in at this point.

Recordkeeping.—Before leaving the site, a record of any modification to the original installation drawing should be made.

System Enhancement

Additional detectors will be installed in the system at appropriate locations to measure turning movements and intersection blockage. An algorithm has been developed to compute these parameters and will be incorporated in the system software in the future.

Also envisioned is the possibility of utilizing a new vehicle detector being developed in-house. This detector is expected to reduce the cost of installation and enable a direct measurement of speed. The detector can be installed in a single saw cut in the pavement extending transversely across an approach lane. The improved detection zone of this detector may make it possible to determine vehicle speed from a single transducer.

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(*2*) "Bus Detector Development Program," Final Report, *Sperry Systems Management Division,* June 1971.

(*3*) Raus, Juri and Tarnoff, Philip J., "Federal Research in Urban Traffic Control," presented at the *Joint ASCE–ASME Transportation Engineering Meeting,* July 26, 1971.

Minimizing the Hazard of Restricted Visibility in Fog

Reported by RICHARD N. SCHWAB,
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OFFICE OF RESEARCH

THE purpose of this article is to briefly describe the nature of fog and its formation; effects of fog on driving and accidents; current fog abatement techniques; and possible guidance systems to aid drivers in minimizing the hazards encountered in fog.

The Nature of Fog and Its Formation

Fog is a visible concentration of small water droplets averaging between 10 to 20 microns in diameter—depending on fog type—that are in contact with the ground or close to it so that visibility is seriously affected. By meteorological definition, fog reduces the visual range to less than 3,300 feet (1 kilometer); however, even a dense fog by meteorological standards—visual range less than 1,300 feet—may not have any significant effects on driving performance.

Various mechanisms involving energy, heat, and moisture all contribute to fog formation (*1*).[1] Specific mechanisms are associated with specific kinds of fogs. For example, a fog will occur if sufficient condensation nuclei are present in the atmosphere and the temperature/specific humidity conditions are above the curve shown in figure 1. This condition may arise from the cooling of air without altering the moisture content, raising the relative humidity by evaporation of rain droplets, or by the mixture of two parcels of air with different temperatures and relative humidities. It is obvious that the formation of most fogs represents a complex and delicate balance of favorable meteorological conditions together with sufficient hygroscopic nuclei in the atmosphere to encourage condensation. This explains the relative rarity and unpredictability of fog and why it tends to be particularly troublesome in areas where industrial activities produce an abundance of nuclei in the effluents.

Figure 2 shows the average number of days annually with some period of dense fog (*2*); that is, less than 1,300 feet visibility. Fog in this density range may or may not be significant for highway operations; however, the figure is included here simply to show the geographical distribution of fog. As can be seen, fog is rarely a problem in the southwest and only an occasional problem in the Great Plains. On the other hand, fog occurs frequently along the west coast, in the Appalachian Mountains, and in much of New England. At times it is dense enough locally to affect traffic behavior. The localness of fog is itself a major part of the problem, because driving in and out of small fog banks can be more dangerous than a more general reduction in visibility.

Many fogs are of short duration in local areas. For example, figure 3 illustrates conditions at Newark Airport where approximately one-half of all dense fogs (¼ mile or less) endure for less

[1] Italic numbers in parentheses identify the references listed on p. 56.

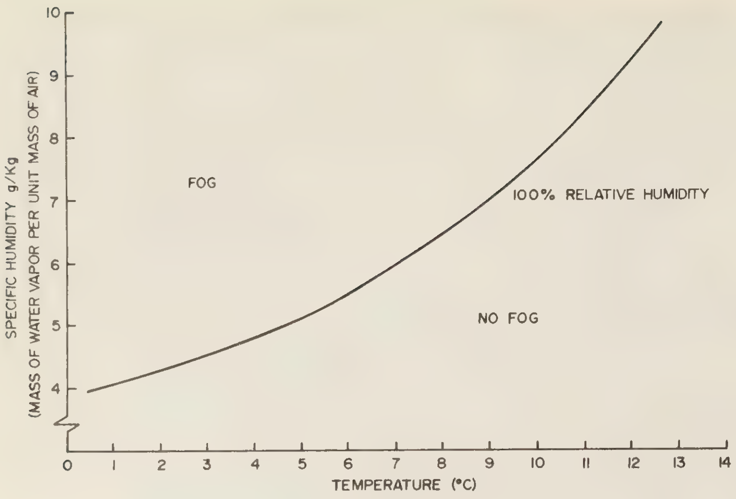

Figure 1.—Atmospheric saturation curve (2).

than 1 hour (*3*). The median duration of denser fogs is about 1½ hours. This is contrary to popular belief that most fogs last many hours, which is probably related to the driver's lack of knowledge as to when fog density limits visibility more severely than the geometric design of the roadway which he is traveling. This factor probably leads to an overstatement of the fog accident problem in minds of the general public.

Effects of Fog on Driving and Accidents

An Australian study (*4*) indicates that for conventional type roads, fog reduces the accident rate by 6 to 10 percent with the largest reduction in the more severe categories of accidents. Although accident-rate data for fog accidents are not available in this country, a similar trend toward less severe accidents in fog than in clear weather conditions is evident in the following table:

Motor-vehicle accidents in fog [1]

	Rural only percent	Total percent
Fatal accidents	1	2
All accidents	2	3

[1] "1962 Accident Facts," *National Safety Council*, Chicago.

The decreased percentage of fatal accidents in fog as compared to all accidents has been attributed to the driver's awareness of fog as a hazard, but the slight speed reduction observed on conventional highways in fog may also contribute, particularly with respect to reducing the severity of accidents.

For freeways, fog has proved to have the opposite effect. A California Transportation Agency study shows that the fatality rate for fog accidents on freeways was almost twice that of nonfog accidents (*5*). A study of California freeway accidents shows that probability of a multiple-vehicle accident was greater in fog than in clear weather, particularly when five or more vehicles were involved (*6*). Fog had little effect on the mean number of vehicles per accident because there were also more single-vehicle accidents in fog and, even in fog, 98 percent of all accidents involved four vehicles or less. However, as shown in table 1, neary two-thirds of all accidents involving nine or more vehicles occurred in fog. These accidents accounted for less than 1/100 of 1 percent of all accidents and about ¼ of 1 percent of fog accidents. The multiple-vehicle accident because of its spectacular nature is widely reported in the news media, giving the impression that accidents are widespread under fog conditions.

Measurements have shown that traffic behavior does not change significantly when visual range is reduced by fog, except for a slight reduction in average vehicle speed under some conditions (*2, 7*). Because of the reduction in visibility, however, there is an increased probability of overdriving the safe-stopping distance. For free-flowing traffic operating on higher speed facilities with good geometric design, there appeared to be no consistent change in speed variability, lateral position, or collision course time (vehicle headway and speed differential with lead vehicle) which could be directly related to visibility restrictions caused by fog.

Figure 2.—Days with some dense fog per year—one-fourth mile or less visibility (2).

Fog Abatement

Dry ice seeding and other techniques have successfully dispersed cold fog; that is fog with liquid water droplets colder than 32° F. (*2*). However, such fogs comprise only a small fraction of all fogs in the continental United States. Dry ice seeding might be useful at a few highway intersections with high traffic volumes in a limited area of the Northwest.

Most fogs in the United States occur at temperatures above 32° F. and in the denser forms usually involve industrial pollution. Presence of pollution particles in the air will not in itself cause fog. However, when atmospheric conditions are right for the formation of fog, hygroscopic particles present in most industrial effluents will increase the density of the fog. Therefore, reductions in industrial pollution should decrease the occurrence of very dense fogs which are a safety problem for motorists. The clean air standards set forth by the Environmental Protection Agency are leading in that direction.

Efforts to achieve a reliable warm fog dispersal capability which

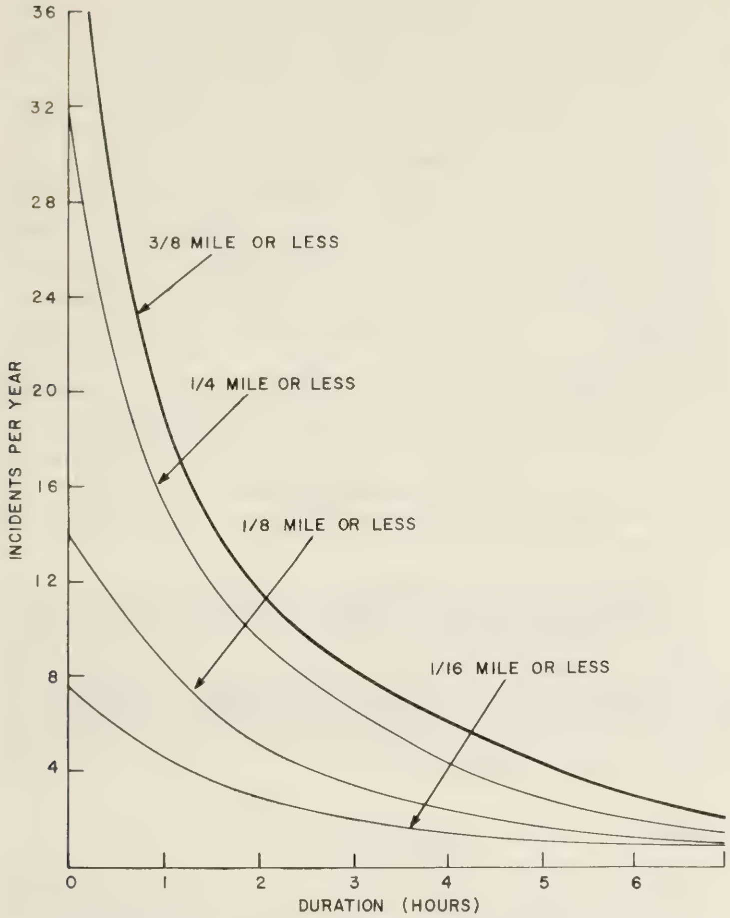

Figure 3.—Incidents of reduced visibility at Newark Airport— Jan. 1, 1956, to Dec. 31, 1965 (3).

might be economically feasible for highway use are far from encouraging. Four general fog dispersal techniques have been attempted: (1) Thermal (evaporation of droplets), (2) chemical (evaporation and/or altering drop size), (3) electrical (coalescence of charges droplets), and (4) mechanical methods. A recent review of this research is contained in NCHRP Report 95 (*2*). Fog dispersal of techniques require large installations, standby, and maintenance expenses, and are often ineffective in dissipating the fog when it occurs. These techniques may be feasible at busy intersections or in other limited areas.

The relatively short persistence of most fogs limits the utility of portable dispersal equipment and installations which require long startup times. Another limiting factor with portable dispersal equipment is the requirement for repeated application to the same roadway section. For example, with a 5-knot wind at 45° to the centerline and a device which initially clears a 100-foot-wide path, fog would begin closing in again within approximately 10 seconds. Therefore, if a 60-second repeated application cycle is required to keep the roadway above some minimum visibility level during a period of dense fog, a 2-mile section of freeway between interchanges might need as many as eight vehicle-mounted dispersal devices.[2]

[2] Assuming 5 miles of travel per vehicle during each dispersal cycle at an average speed of 40 miles per hour.

Natural vegetation—judicious landscaping with some forms of tree stands—has been applied in some specific locations to prevent shallow fogs from drifting over the road (*2*).

Guidance Systems

A variety of methods designed to assist drivers during fog have been proposed and some have been experimentally tried. These include both active and passive type guidance systems. Because of the clear economic infeasibility of justifying active type guidance systems, such as *automated highways*, as possible solutions to the fog problem alone, they will not be discussed here. These types of systems might be justifiable for general purposes and, if so, would provide a solution to the fog problem by eliminating the driver from the control loop.

Under certain nighttime conditions some highly directional types of fixed-lighting systems have proved to be effective in providing additional guidance information in fog (*8*). However, as is shown in figure 4, the fog accident problem is particularly severe after dawn between the hours of 6 and 9 a.m., with the peak occurring about 7:30 a.m. (*1*). Approximately 50 percent of the fog accidents occur in daylight. Fixed-lighting systems can be designed (*9*) to be effective for 50 percent of the fog accidents which occur at night. However, the additional expense of such equipment would probably not be recovered from the resulting reduction in accidents. Conventional types of street lighting may be useful in light to moderate fogs, but are of little help in a dense fog.

Present reflectorized pavement-marking techniques result in only a slight increase in visibility during daytime fog and have virtually no effect on traffic behavior. Inset *pancake* marker lights have been suggested to provide guidance. They are relatively expensive and do not provide any information on stopped vehicles. Perhaps such a display technique combined with the information on lane occupancy obtained from instrumentation similar to the *passing-aid system* would work.

Table 1.—Multivehicle accidents in fog on California highways—1965–68 [1]

Vehicles per accident (number)	All accidents (number)	In fog			
		Accidents (number)	Percent of all accidents	Percent of vehicles involved	Cumulative percent of vehicles involved
1.......	149, 798	3, 631	2. 4	20. 3	100. 0
2.......	262, 346	4, 911	1. 9	54. 9	79. 7
3.......	38, 344	786	2. 0	13. 2	24. 8
4.......	7, 623	223	2. 9	5. 0	11. 6
5.......	1, 708	81	4. 7	2. 3	6. 6
6.......	471	43	9. 1	1. 4	4. 3
7.......	160	23	14. 4	. 9	2. 9
8.......	47	15	31. 9	. 6	2. 0
9 or more..	39	25	64. 1	1. 4	1. 4
Total...	460, 536	9, 738	2. 1	....	....

[1] NCHRP Report No. 95.

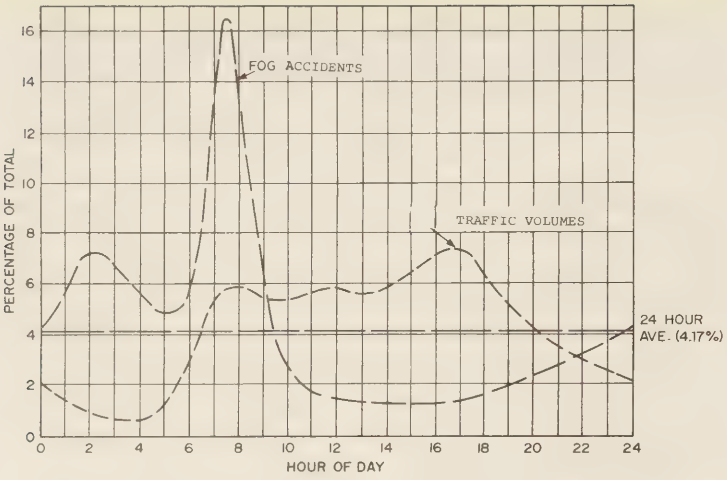

Figure 4.—Hourly distribution of traffic volumes and fog accidents (6).

Results of research on vehicle rear-lighting systems indicate that current vehicle rear lights are ineffective in fog, especially during daytime. Increased candlepower would be desirable and the National Highway Traffic Safety Administration appears to be moving in that direction. The major problem concerns the control and possible misuse of a two or more level tail-lighting system.

The most successful of the ideas involves use of variable message signs to warn drivers about fog conditions ahead and to advise them as to desirable operating speed. Although these signs have little influence on mean operating speeds, they do reduce speed variance when the sign is set at approximately the mean speed of traffic (*7*). If the signs are set much below the prevailing speed, a bimodal speed distribution results increasing the likelihood of rear-end collisions. Part of the reason for these results may be the lack of reliability of information provided by such signs in the past. Particularly, where manual changing of speed limits or folding advisory signing was required, the messages were often exposed long after the reduced visibility condition ended. Therefore, many drivers may have assumed that such signing is meaningless.

A major installation of remotely controlled warning signs is being evaluated in Oregon at the Murder Creek interchange on Interstate 5 (*10*). There are three large overhead signs in each direction with the final sign at the point of maximum accident occurrence. The variable speed message is controlled on the recommendation of a State police officer located in the signed area and is based on the distance he can see and traffic flow in the area. Research is currently investigating traffic and fog detection equipment for use in automating control of the signs.

Preliminary reports indicate that the Oregon installation is having a beneficial effect in terms of accidents and traffic flow. Traffic flow parameters, such as mean speed, speed variance, and headway, may be more useful in determining required information to be displayed to drivers than devices for detection of fog density. Use of optical/electronic devices for detection of fog appears to be too expensive for widespread use and too sensitive to small changes in local conditions within a few yards of the measurement station. Research (*11*) underway is attempting to relate the output of such a device to a meaningful fog index for drivers.

The Federal Highway Administration is currently planning research aimed at developing a speed advisory system which will inform drivers of the current status of other vehicles' speed on the road ahead but beyond the limit of the drivers' available sight distance. Such a system might involve a simple fog-no-fog detector for system activation and a speed sensor with a simple roadside sign indicating an advisory speed. The speed would be set at approximately the mean speed of traffic one-fourth to 1 mile ahead. The logic devices for controlling the system should probably be interconnected so that no sign calls for a speed that is more than 10 to 20 miles per hour higher than the next sign the driver will see as he continues down the road, except under exceptionally critical conditions.

The installation of such a system should reduce speeds of traffic gradually and should aid in reducing multivehicle secondary accidents. Because the system will be designed to alert drivers to any slowing of traffic ahead regardles of cause, it is expected that the system will be useful for many situations in addition to those produced by fog.

Summary

There is no technology presently available which will solve the fog problem in a cost-effective manner. Present research in the area of warning-advisory signing for fog appears to hold significant potential. The only real safe advice at present is—if the situation gets bad enough, close the road.

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Figure 1.—Eroded cut slope.

Environmental Quality Assurance Through Demonstration Projects

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A relatively new and responsive aspect of the Federal-aid highway program, directly serving the State highway departments and other governmental agencies, is the Region 15 Research and Development Demonstration Projects Program. Its mission is to accelerate the general adoption and actual use of the results of nationwide highway research, development, and innovative engineering practice. Its method is to translate these results into operating procedures and to demonstrate their use to State highway departments and other governmental agency personnel. It also provides special training opportunities for Federal Highway Administration (FHWA) and State highway department engineers.

A significant portion of the demonstration projects program is directed at assuring and oftentimes improving the environmental quality of our Nation's highways. Specifically, there are four demonstration projects devoted to this purpose.

Serrated Soft-Rock Cut Slopes

The first of these projects is the demonstration of the use of the serrated soft-rock cut slope technique of design and construction to: (1) Reduce sheet erosion and its associated adverse siltation and sedimentation effects, (2) stabilize and improve the appearance of highway cut slopes, and (3) reduce highway maintenance. Elimination of unsightly eroding cut slopes, such as the one shown in figure 1, is the objective. The construction of a series of 2- to 4-foot horizontal and vertical steps into the cut slope, as shown in figure 2, is all that is involved These serrations provide an ideal seedbed for the generation of vegetation and provide for the control and reduction of sheet erosion during construction, and afterwards on a continuing basis. The serrations gradually disappear and vegetation is well established, as shown in figure 3.

This design and construction technique has been demonstrated through a variety of media including a field conference, several reports, presentations at regional AASHO design meetings, and a nationwide touring slide show. A 15-minute colored movie description of the serrated cut-slope design and construction technique has been produced and distributed to the FHWA regional offices where it is available for States and other agency viewing. The feedback is that out of a total of 37 States having suitable material conditions, 15 States have, are, or will be building these slopes within the next year. Idaho and Maryland have some outstanding serrated cut-slope installations. There is no reason why the remaining States could not have the same. While the serrated cut-slope technique was initially developed and most successfully used in soft-rock material, it has produced successful results in the glacial till areas of the Nation. California is presently researching its application in highly cohesive soils using large serrations.

Erosion Control With Wood Chips on Newly Graded Areas

The second closely related project is the demonstration of the practicality of salvaging and converting woody vegetation, usually

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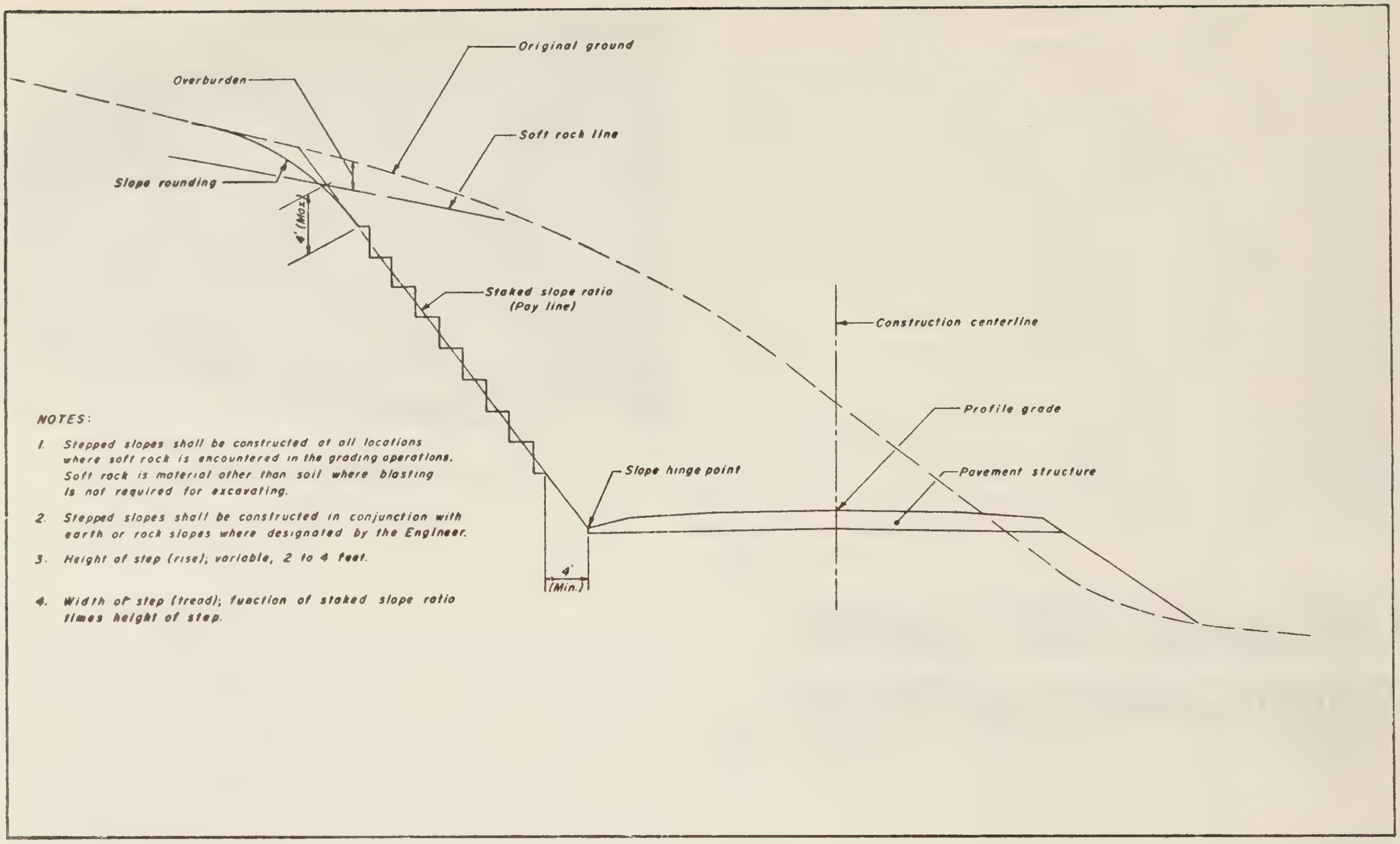

Figure 2.—Stepped slope for cuts.

wasted during site-clearing operations, into wood chips for erosion control on newly graded areas. This procedure involves taking the woody vegetation available from a highway clearing operation as shown in figure 4, converting it into wood chips (fig. 5), placing about 50 pounds of nitrogen on each ton of chips and placing the mixture on newly graded fill and cut slopes in approximately 2-inch layers, as shown in figure 6. Experiments show that the chips effectively prevent erosion on slopes up to 1:1. In about 2 years, the chips decompose nicely to fertile mulch material and natural regeneration of a slope occurs, or seeds can be placed over, under, or in the chips during initial placement, or subsequently, to produce an adequate grass cover.

An interim report on the use of wood chips has been distributed nationally and a 16 mm. color movie on the use of wood chips for erosion control has been just recently distributed to the FHWA regional offices and made available for State and other highway agency viewing.

Roadside Ditch Erosion Control

The third demonstration project in this area is directed at improving the appearance and safety of the many miles of our Nation's highways that are impaired by badly eroded roadside ditches, as shown in figure 7.

The first method to be demonstrated was tested and evaluated by the Louisiana Department of Highways under a Highway Planning and Research project and involves the use of Fiberglas roving. This method entails the regrading and reshaping of the eroded ditch into a uniform section with fairly flat slopes (fig. 8), normally with material from the back slope. The regraded sections are then treated with lime, seeded, fertilized, and covered with Fiberglas roving (fig. 9). Finally the roving is tacked down with asphalt. If properly installed, grass cover will be successfully established and adequate erosion control attained, resulting in a safe and esthetically pleasing roadside, as shown in figure 10. This method of ditch-erosion control will be demonstrated this fall.

Figure 3.—Stepped slope with gradually disappearing serrations.

Figure 4.—Clearing vegetation to be cut into wood chips.

Figure 5.—Chipping machine.

Figure 6.—Wood chips placed on slope in 2-inch layers.

Figure 7.—Badly eroded ditch.

Figure 8.—Ditch graded for placing of roving material.

Figure 9.—Regraded section being covered with Fiberglas roving.

Waste Products as Highway Construction and Maintenance Materials

The last and possibly most interesting demonstration project in environmental quality is the demonstration of the practical use and economic feasibility of waste products as roadbuilding and maintenance materials.

This project therefore relates to the improvement of the total environment through the utilization of waste materials in roadway construction. The first phase of this demonstration project was the physical construction, testing, and evaluation of waste products as roadbuilding materials at the TRANSPO 72 site at the Dulles International Airport. One of the parking lots, approximately 100 acres in area, was surfaced with a mixture of fly ash waste, sulfate sludge, and hydrated lime. Sulfate wastes exist from steel plants, acidic effluent from chemical plants, trapped and washed sulfur oxide gases from coal-burning powerplants, and mine acid drainage from coal mines. Fly ash is a finely divided mineral product resulting from the burning of pulverized coal. The sulfate wastes and fly ash components were stockpiled, while the hydrated lime was contained in the conventional silo, as shown in figure 11. The three components were combined in a conventional plant equipped with the standard pugmill. The manufactured product, which had the consistency of a soil-cement mixture, was hauled to the construction site in conventional dump trucks and placed in a 7-inch uncompacted depth with a conventional roadway material spreader, as shown in figure 12. The mixture was compacted to an in-place depth of 5 inches using conventional rolling equipment, predominantly a vibratory steel wheel roller (fig. 13), and finished off with conventional motor graders. The manufactured product did successfully serve as a base material for the TRANSPO 72 exposition and should serve to help develop refined design and application techniques for the demonstration of the use of the specified waste products as roadbuilding materials on regular highway projects.

These four demonstration projects are examples of how the Federal Highway Administration is insuring and oftentimes improving the environmental quality of our highways and our entire Nation. The Region 15 Research and Development Demonstration Projects Program appears to be one of the most successful avenues for accomplishing this task.

Figure 10.—Restored ditch with grass cover.

Figure 11.—Stockpile of fly ash used in stabilized waste parking areas, Dulles International Airport.

Figure 12.—Stabilized sulfate waste being placed by a material spreader.

Figure 13.—Compacting stabilized waste parking area, Dulles International Airport.

Accident Experience on Speed-Change Lanes of the Interstate Highway System

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Environmental Design and
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OFFICE OF RESEARCH

PAST RESEARCH of the Federal Highway Administration has shown that the Interstate Highway System has a significantly better safety record compared to conventional highways that formerly accommodated traffic now using Interstate highways (*1, 2*).[1] Of the reported accidents on the Interstate System, however, fully two-thirds occur at interchanges, particularly on the crossroads. Interchanges are complex units accommodating the exchange of high-speed traffic between one Interstate highway and another, or between an Interstate highway and a lower speed conventional highway.

Definitions

Speed-change lane.—An auxiliary lane, including tapered areas, primarily for the acceleration or deceleration of vehicles entering or leaving the through traffic lanes. For this study, speed-change lanes always include adjacent main roadways; e.g., acceleration lanes are actually acceleration lanes plus adjacent main roadway.

Acceleration lane.—A speed-change lane for the purpose of enabling a vehicle entering a roadway to increase its speed to a rate at which it can more safely merge with through traffic.

Deceleration lane.—A speed-change lane for the purpose of enabling a vehicle that is to make an exit turn from a roadway to slow to a safe speed before a curve ahead and after it has left the mainstream of faster moving traffic.

Combined acceleration-deceleration lane.—A section between an on-ramp and an off-ramp where an additional or auxiliary lane is built from one ramp to the next. For this study the acceleration and deceleration lanes are called weaving areas.

Mainline units

Between interchanges.—A unit on the Interstate highway not at the interchange, less than 10,000 feet in length and homogenous throughout with respect to its geometry and traffic characteristics.

Between speed-change lanes.—A unit on the Interstate mainline at the interchange and between speed-change lanes.

Highways Units

Acceleration and deceleration lanes play a crucial part in speed transition between interchanges (fig. 1). These units are commonly called speed-change lanes, a term also descriptive of their function. As research has shown, the variance in speed among vehicles using highways creates a greater chance of accidents (*3*). By their very function, speed-change lanes must accommodate great variances in speed. They are, therefore, the object of considerable concern. Thus the purpose of this analysis is to present information relative to accidents at speed-change lanes and, based on this and related accident analyses, to discuss possible techniques for reducing these accidents.

Accidents on Speed-Change Lanes

About 14 percent of all accidents on the Interstate System occur on speed-change lanes, which account for only 5 percent of the mileage of the Interstate System. Table 1 shows that the percentage of accidents on urban speed-change lanes is 15.7 percent of total accidents, although on rural speed-change lanes it is only 9.6 percent. This is primarily explained by the fact that interchanges in urban areas are twice as close as in rural areas (*3*). Other factors are that in urban areas the length of the speed-change lane is generally shorter than in rural areas, and higher traffic volumes in urban areas make the speed-change maneuvers more difficult to execute.

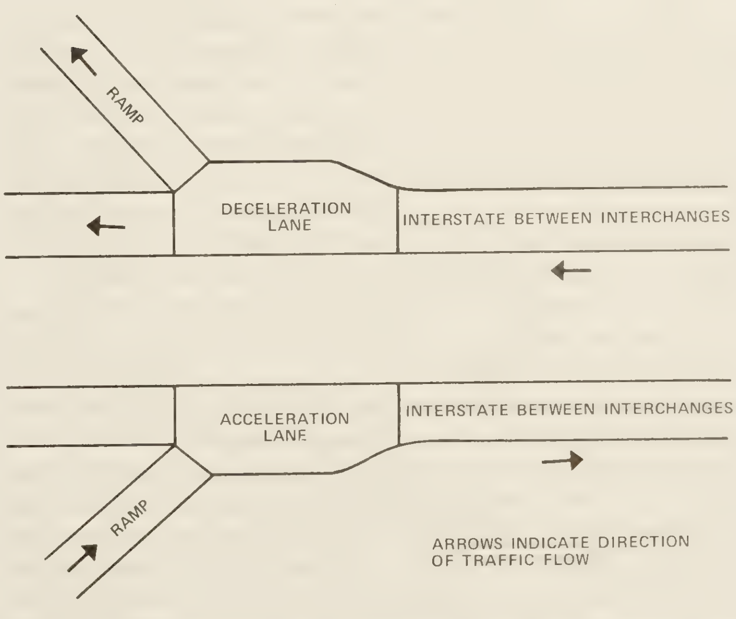

Figure 1.—Acceleration and deceleration lanes as defined in the Interstate System Accident Research Study II.

[1] Italic numbers in parentheses refer to references listed on page 64.

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Table 1.—Accidents by type of Interstate highway unit and type of area

Type of Interstate highway unit	Type of area			
	Urban		Rural	
	Number of accidents	Percent of total accidents	Number of accidents	Percent of total accidents
Acceleration lane	1,991	8.7	458	4.5
Deceleration lane	1,598	7.0	524	5.1
Ramps	2,387	10.5	441	4.3
Mainline between interchanges	5,760	25.3	5,014	49.1
Other [1]	11,038	48.5	3,762	37.0
Total	22,774	100.0	10,199	100.0

[1] Primarily crossroads, also collector-distributor roads and other less common situations.

The severity as well as the number of accidents on a particular type of Interstate highway unit is also of interest. Table 2 indicates that there is little difference in the ratio of injuries per 100 accidents when speed-change lanes are compared with mainline between interchange units. The similarity in the injury ratio is probably due to the compensating effects of speeds on mainline between interchange units and the presence of additional roadside obstructions at speed-change lanes. The number of fatalities per 100 accidents, however, is about 50 percent higher on the mainline between interchange units. This could probably be attributed to the high speeds of vehicles involved in accidents on mainline between interchange units. That is, since fatalities result from the more serious injuries, higher operating speeds on mainline between interchange units result in more serious injuries and hence more fatalities.

When discussing accidents, it is desirable to put the number of accidents in perspective relative to some measure of the exposure to an accident situation; i.e., possibility of an accident occurring. In table 3 exposure is measured in terms of both miles of highway and vehicle-miles of travel. Investigation of speed-change lanes indicates that they had consistently higher accident rates compared to mainline between interchange units when measured either on the basis of the number of accidents per 100 million vehicle-miles of travel or per mile of highway (table 3). Ramps had even higher accident rates than speed-change lanes on a vehicle-mile basis. On a per mile basis, the rate is lower because main roadway traffic included in the definition of the speed-change lane data boosts the vehicle mileage.

In urban areas, acceleration lanes experienced double the number of accidents per mile compared to mainline between interchange units (table 3). For deceleration lanes this figure is almost tripled. In rural areas, although traffic operations are less complex than in urban areas, speed-change lanes also experienced a considerably higher number of accidents per mile than mainline between interchange units. Deceleration lanes again had more accidents per mile than acceleration lanes. As expected, and regardless of the exposure index, all unit types in urban areas had a considerably higher accident experience than similar unit types in rural areas.

In rural areas about 8 percent of accidents that occur on acceleration lanes and the same percentage on deceleration lanes involve one or more vehicles stopped on the roadway or shoulder. In urban areas, the comparable figure is approximately 30 percent for acceleration lanes and 24 percent for decleration lanes. The reasons for this occurrence, although beyond the scope of this study, are due in part to the following factors:

- On acceleration lanes, the driver's limited ability to judge speed and distance of oncoming through traffic limits his ability to judge acceptable safe gaps and frequently results in a stopped vehicle waiting for a safe gap.
- On deceleration lanes, the driver's confusion as to his desired direction and his subsequent stopping on the roadway or shoulder to consult written or printed directions.

Table 2.—Ratio of injuries and fatalities per 100 accidents by type of Interstate highway unit

Type of Interstate highway unit	Number of accidents	Number of injuries	Injuries per 100 accidents	Number of fatalities	Fatalities per 100 accidents
Acceleration lane	2,449	1,817	74.2	48	2.0
Deceleration lane	2,122	1,534	72.3	49	2.3
Ramps	2,828	(2)	(2)	(2)	(2)
Mainline between interchanges	10,774	8,192	76.0	344	3.2
Other [1]	14,800	(2)	(2)	(2)	(2)

[1] Primarily crossroads, also collector-distributor roads and other less common situations.
[2] Not available.

Table 3.—Accident rate by type of Interstate highway unit and type of area.

Type of Interstate highway unit	Type of area			
	Urban		Rural	
	Number of accidents per 100 mvm [1]	Number of accidents per mile	Number of accidents per 100 mvm [1]	Number of accidents per mile
Acceleration lane	174	5.0	76	1.2
Deceleration lane	186	6.5	137	2.0
Ramps	551	3.8	253	.9
Mainline between interchanges	130	2.4	61	.8
Other [2]	(2)	(2)	(2)	(2)

[1] 100 mvm: 100 million vehicle-miles of travel.
[2] Comparison not meaningful because included in these data are terminal areas, at-grade intersections, and other sections with large areas but very short and/or irregular lengths.

• Vehicular or driver emergencies necessitating stopping of vehicles on the shoulder or roadway.

On mainline units between interchanges, the proportion of accidents involving one or more stopped vehicles is somewhat lower: 6 percent in rural areas and 23 percent in urban areas. On mainline units between speed-change lanes at interchanges, the comparable figures are 6 and 33 percent, respectively, for rural and urban areas. These results again indicate the apparent problems associated with the decisionmaking processes necessary at an interchange, particularly in urban areas.

Further breakdown of accidents on speed-change lanes shows that 69 percent of the accidents on acceleration lanes are rear end or same direction sideswipe collisions. On deceleration lanes this figure is 57 percent. The next largest category, single-vehicle accidents, account for 26 percent of the accidents on acceleration lanes and 34 percent on deceleration lanes. The remaining 5 and 9 percent of the accidents, on acceleration and deceleration lanes, respectively, are distributed among angle collisions, head-on or opposite direction sideswipe accidents, and pedestrian accidents. The latter three accident categories are minimal on Interstate highways because full control of access, existence of speed-change lanes, and separation of opposing flows nearly eliminate angle-type crossing maneuvers, conflicts between opposing vehicles, and conflicts with pedestrians, all of which occur frequently on conventional highways.

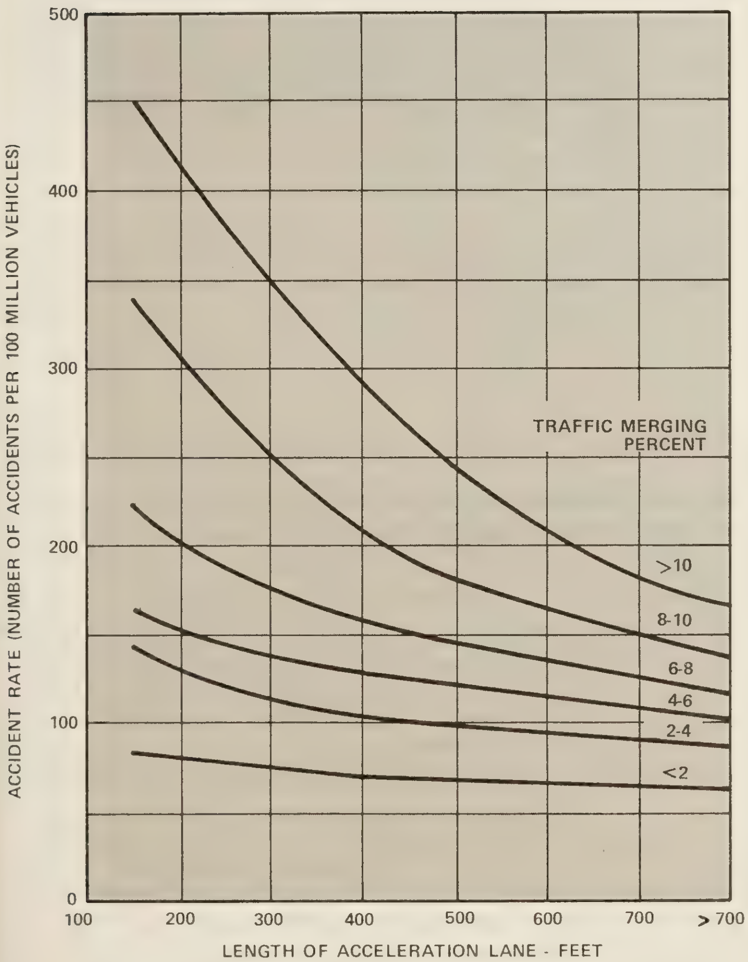


Figure 2.—Accident rate by length of acceleration lane and percentage of traffic merging.

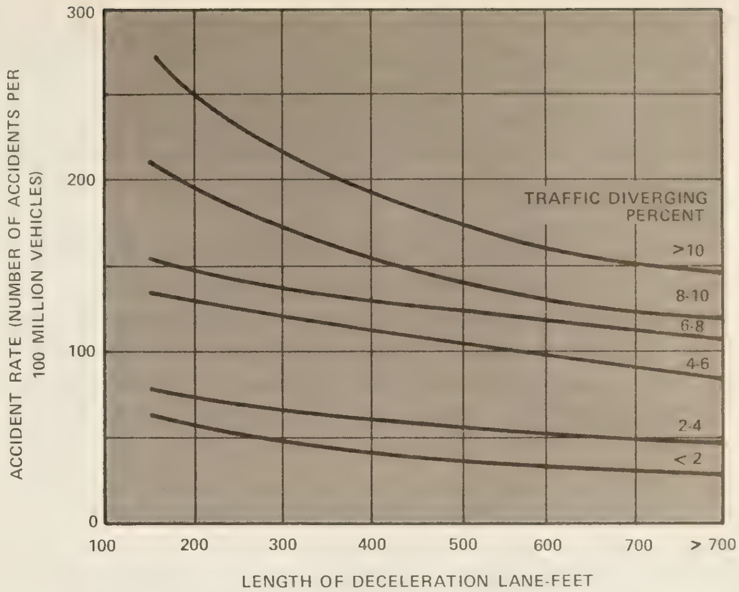


Figure 3.—Accident rate by length of deceleration lane and percentage of traffic diverging.

The question arises as to what can be done to improve the operation of speed-change lanes and thereby reduce their accident potential. Some suggested techniques for improving operation of speed-change lanes will be discussed in the next section.

Improving Operation of Speed-Change Lanes

A Federal Highway Administration report (*4*) presents the results of a mathematical modeling effort designed to indicate the relationship between accidents and many geometric and traffic characteristics of the Interstate Highway System. Many types of units were modeled, including acceleration lanes, deceleration lanes, and ramps. The general results of this analysis indicate that extensive changes to the geometrics on the Interstate will not greatly alter the accident experience of the system.

Results of this analysis, however, did indicate that the geometric variables on deceleration lanes, which contributed most to the reduction of accidents, were paved right shoulders, increased minimum stopping sight distance, and presence of delineators. On acceleration lanes these variables were paved right shoulders and decrease in maximum curvature.

The models developed for ramps illustrate that increased length of the speed-change lane associated with the ramp could be expected to decrease the average number of accidents occurring on the ramp.

Additional study (*5*) concerned specifically with the length of speed-change lanes indicates that increased length of these units will decrease the accident rate on both acceleration and deceleration lanes. Figures 2 and 3, based on data from this study, illustrate this finding and show that speed-change lanes greater than about 600 feet are especially desirable when the percentage of traffic merging and diverging is greater than about 8 percent. There is also a clear indication that acceleration lanes need to be longer than deceleration lanes; this is in line with modern freeway design standards.

Another type of interchange unit also of consequence is the combined acceleration-deceleration lane or weaving area as defined by figure 4. Analysis and mathematical modeling of this unit has also been undertaken. Results of this study (fig. 5) indicate that increased length was the single most important nontraffic variable which could be expected to reduce accidents on this type of unit (*6*).

Reasons for the findings concerning the relation between accidents and length of speed-change lanes are relatively clear. The longer the length of either acceleration or deceleration lane, the more time the driver has to adjust his speed. Consequently, the variance in speed at any particular point on the speed-change lane will decrease, and chances of an accident occurring will also decrease.

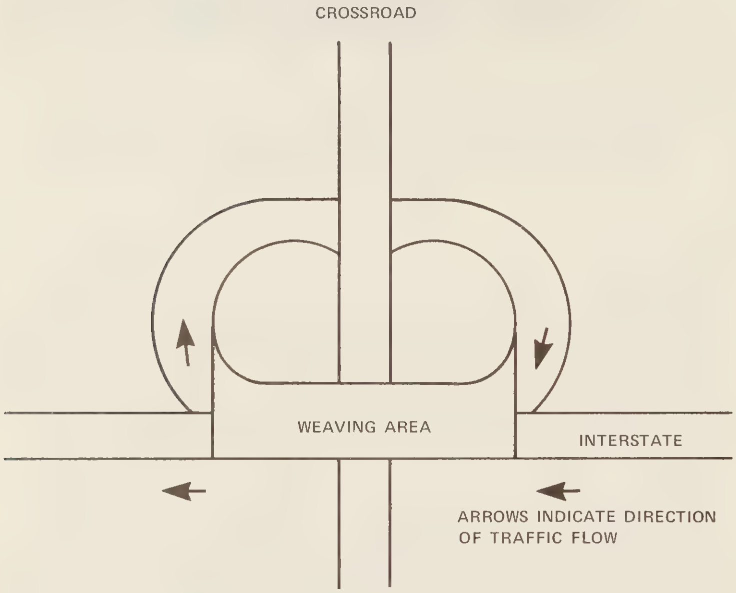


Figure 4.—Weaving areas as defined in the Interstate System Accident Research Study II.

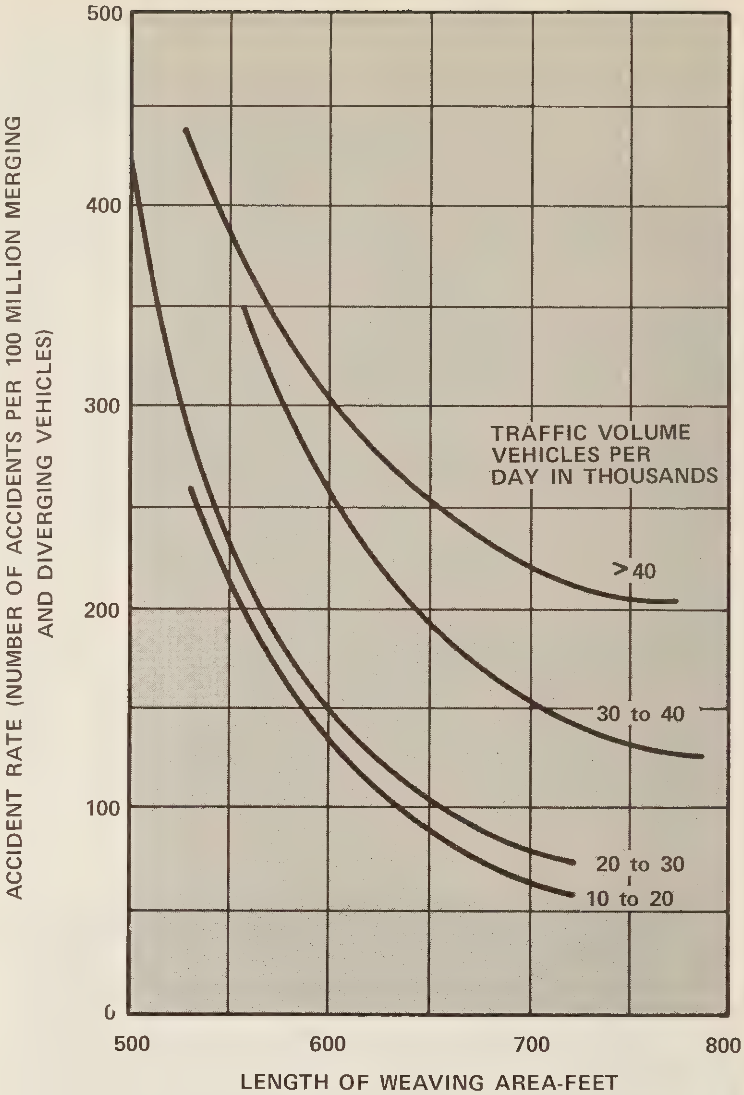


Figure 5.—Accident rate by length of weaving area and traffic volume.

REFERENCES

(*1*) Byington, S. R., "Interstate System Accident Research," PUBLIC ROADS, vol. 32, No. 11, December 1963.

(*2*) Cirillo, J. A. et al., "Interstate System Accident Research–Study I," vol. 1, FHWA, Government Printing Office, October 1970.

(*3*) Cirillo, J. A., "Interstate System Accident Research–Study II," Interim Report II, PUBLIC ROADS, vol. 35, No. 3, August 1968.

(*4*) Cirillo, J. A. et al, "Analysis and Modeling of Relationships Between Accidents and the Geometric and Traffic Characteristics of the Interstate System," *FHWA*, Government Printing Office, August 1969.

(*5*) Cirillo, J. A., 'The Relationship of Accidents to Length of Speed-Change Lanes and Weaving Areas on Interstate Highways," *Highway Research Record* No. 312, 1970, pp. 17–32.

(*6*) Cirillo, J. A. Master's Dissertation in the Library at the Catholic University of America.

Electronic Computer Program Library

Reported by the Implementation Division, Office of Development

Material concerning specific electronic computer programs, developed in FORTRAN for use in highway engineering, is available through the Implementation Division Electronic Computer Program Library. Most of these programs have been developed either in-house or by State highway departments under the sponsorship of the Office of Development. These programs are available to the public from the National Technical Information Service (NTIS).

When ordering programs include document PB numbers and program titles to insure prompt service. The price is $3 for each paper copy and 95 cents for a microfiche reproduction of each document. Prepayment is required. Checks should be made payable to the National Technical Information Service. Holders of NTIS deposit accounts may have their orders billed to their account by giving the account number. The mailing address is National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

CRITICAL PATH METHOD REPORTS

Program A–4 (PB 168740).—A system or series of programs designed for Critical Path Method (CPM) calculations. The CPM Calculations Program, using any time unit, calculates the project cost, scheduled early and late starts and finishes, and total and free float of each activity. Program produces output used by two additional programs in the system. The CPM Calendar Dating Program converts the CPM Calculations Program output to calendar dates when the time unit is working days. The CPM Time-Sequence Plot Program converts the CPM Calculations Program output to a calendar basis plot of the duration and total float of each activity when the time unit is working days.

HYDRAULIC ANALYSIS OF CIRCULAR CULVERTS

Program HY–1 (PB 168715).—This program is used for the hydraulic analysis of circular pipe culverts for given hydrological data and site conditions. The program produces number of pipes, pipe sizes, headwater, and outlet velocities for inlet conditions and outlet conditions. Outlet control calculations make use of backwater computations, whenever necessary, to compute headwater.

HYDRAULIC ANALYSIS OF PIPE-ARCH CULVERTS

Program HY–2 (PB 168716).—A program used for hydraulic analysis of pipe-arch culverts—the culverts which satisfy the hydrological data and site conditions for inlet control and outlet control. Output includes number of pipes, span, rise, headwater, and outlet velocities. Outlet control calculations make use of backwater calculations, whenever necessary, to compute headwater.

HYDRAULIC ANALYSIS OF BOX CULVERTS

Program HY–3 (PB 168717).—Program used for hydraulic analysis of box culverts for given hydrological data and site conditions. Program determines the size of culvert which satisfies the hydrological data and site conditions for inlet control and outlet control. Output includes number of barrels, culvert width, culvert height, headwater, and outlet velocities. Outlet control calculations make use of backwater calculations, whenever necessary, to compute headwater.

HYDRAULICS OF BRIDGE WATERWAYS

Program HY–4 (PB 168718).—Program is used for the hydraulic analysis of waterways at bridge sites, and for determining information on backwater that can be produced or caused by a bridge. The program consists of two parts: part one analyzes the open channel or natural stream section and produces typical state-discharge information; part two analyzes the constricted opening and determines water velocities and backwater heights for given discharges.

FLOOD RECORD COMPILATION AND FREQUENCY PLOT

Program HY–5 (PB 176539).—Program describes a method whereby annual maximum flood records can be stored, retrieved, and displayed for use by engineers involved in the design of a stream crossing. Data are the annual flood data published by the U.S. Geological Survey in their water supply papers. Graphical display of data is based on a Gumbel recurrence interval. The computer system was developed to allow for required updating of the frequency plots. Manual updating of the plot is time consuming due to the need for recalculating the return period each time a new flood record is added. Through the use of the computer, the flood record can be updated and the frequency plot generated automatically.

POLYNOMIAL CURVE FITTING BY LEAST SQUARES

Program M–1 (PB 168729).—Program is used for the curve fitting of experimental data that has one dependent variable and one independent variable. Program will calculate the coefficients for the degree of polynomial equation desired for the input data, the residuals, and the standard error of estimate. Using a weighting factor in conjunction with the dependent and independent variable is permitted.

RENUMBERING OF FORTRAN STATEMENT NUMBERS

Program M–2 (PB 176538).—Function of program is to replace old statement numbers in an original FORTRAN source deck with new sequential statement numbers. All statement numbers appearing are converted to a new system. The result is a new FORTRAN listing and a reproduced source deck containing the new sequential statement numbers.

Report contains two listings of the renumbering program. One listing shows the statement numbers in an irregular pattern of sequencing; the other listing shows the statement numbers in a sequential pattern after the source deck was processed with the renumbering program.

ANALYSIS AND DESIGN OF WELDED STEEL GIRDERS

Program ST–9 (PB 168747).—Program used for analysis and design of simply supported welded steel girders in accordance with the 1961 AASHO Standard Specifications for Highway Bridges. It is applicable to the design of symmetrical girders with uniform flange plate widths, but with varying flange plate thicknesses. It is applicable to the design of carbon steel or low alloy steel girders with or without web plate stiffeners.

SIMPLE BEAM ANALYSIS

Program ST–10 (PB 168737).—Program used for computation of shear, moment, required section modulus, deflection and stress due to uniform or concentrated loads at any number of points. Program provides answers for five typical beam conditions with uniform or variable moment of inertia. For truck loading, the truck is placed so as to produce maximum positive and negative moments and the deflections for these positions. Deflection of continuous beams can be determined due to applied loading and previously determined reactions.

COORDINATE TRANSFORMATIONS

Program SU–4 (PB 179320).—Previously, computer programs were written in FORTRAN II for converting geographic coordinates to State plane coordinates or the inverse for use on the IBM 1410 (12K) data processing system. Two separate programs were needed for the transformations because of the limited core storage available. One program performed the forward and inverse computations for the Lambert conformal projection and the other for the transverse Mercator projection. This program combines both methods into one calling program and six subroutines.

STEREOCOMPARATOR COORDINATE REDUCTION

Program R–0100 (PB 198590; Source Deck PB 198589).—This computer program relates to analytical aerial triangulation and is to be used for reducing stereocomparator measured coordinates from photographs with four side fiducials. It consists of a main calling program and 20 subroutines.

ANALYTICAL STRIP TRIANGULATION

Program R–0200 (PB 198592; Source Deck PB 198591).—A computer program representing the combination of two previously published programs for analytical aerial triangulation. The first is titled "Aerotriangulation: Image Coordinate Refinement" by M. Keller and G. C. Tewinkel, U.S. Coast and Geodetic Survey Technical Bulletin No. 25, March 1965. The second is titled "An Introduction to Analytical Strip Triangulation with a FORTRAN Program" by G. H. Schut, National Research Council of Canada AP–PR34, December 1966.

ANALYTICAL STRIP TRIANGULATON AND ADJUSTMENT

Program R–0300 (PB 198594; Source Deck PB 198593).—This program is a sequel to Program R–0200 in that it combines R–0200 with the previously published program "A FORTRAN Program for the Adjustment of Strips and Blocks by Polynomial Transformation" by G. H. Schut, National Research Council of Canada AP–PR33, February 1968. This combined program permits the computation of ground *X, Y, Z* coordinates derived from comparator measurements made on aerial photographs in a single pass operation.

PRETENSIONED GIRDER DESIGN

Report No. FHWA–RD–72–17 (PB 210140).—This computer program designs pretensioned prestressed girders, Types I through IV, for either draped or staight strands using input parameters such as beam type, wire size, span length, and girder spacing as described by the engineer.

Strand patterns are at 2-inch centers both vertically and horizontally. The program computes the required number of strands and proceeds to design the girder for standard AASHO highway loadings plus special loading. If draped strands are required to keep stresses within allowable limits the program will drape the strands at the 1/3 points of the beam.

The process is iterative, and strands are added until a satisfactory girder is designed, or until the largest wire size (9/16 inch, 270 k.s.i.) has been exhausted. Provision has been made for a uniform load, such as a curb load.

The program checks the beam under ultimate load, computes horizontal shear and required stirrup spacing. It prints out deflections under initial and final conditions.

Computer-Generated Perspective Plots for Highway Design Evaluation

Reported by the Implementation Division, Office of Development

A new development for highway design evaluation—computer-generated perspective plots—is now available. The technique involves a computer software system capable of generating perspective views from an existing highway design data base. In addition, photo-plot montage and animation techniques that can be adapted for use with a cathode-ray tube have been developed and included in this package. Thus a visual simulation of a drive along a proposed highway can be presented in the form of a motion picture for evaluation by various groups involved in highway location and design.

Today, not only are highway engineers concerned with highway design, but safety experts, behavioral scientists, environmentalists, and lay pressure groups also enter into the decisionmaking process when new roads are in the location and design stages. Certainly all of these people are concerned about the effects of highways on the environment and the public. And by being able to see a simulated highway view prior to construction, they can offer comments regarding the proposed design with respect to safety, esthetics, and environmental considerations.

Highway engineers will find perspective plots valuable for evaluating design features of a proposed highway. Problems such as hilltop curves, confusing intersections, and inadequate sight distances can be eliminated before construction begins. At the same time photo-plot montages enable designers to obtain a visual perspective of the road as it relates to the scenic beauty of the countryside.

Presently, a report describing the methodology involved in this system, along with the four related computer programs, written in FORTRAN IV, are available from the National Technical Information Service (NTIS), Sills Building, 5285 Port Royal Road, Springfield, Virginia 22151. Each program can be implemented on most computer systems with little difficulty. A brief abstract of the report and of each program follows:

COMPUTER-GENERATED PERSPECTIVE PLOTS FOR HIGHWAY DESIGN EVALUATION

Report FHWA–RD–72–3 (PB 208097).—Techniques and mathematical basis for producing computer-generated perspective plots of highways for design evaluation are described in this report. Plots are either produced on a digital incremental plotter or displayed on a cathode-ray tube (CRT) or microfilm recorder. Animation effects may be produced by photographing sequences of views as produced on the CRT displays or as recorded on microfilm.

The methodology for producing photo-plot montages, which consists of superimposing computer-generated plots on ground photographs, is given. Results of field test evaluations are presented for photo-montages produced by using a phototheodolite and also nonmetrical cameras. The next four computer programs are required to implement the methodology described in this report.

TEMPLATE CONVERTER PROGRAM

Report FHWA–RD–72–5 (PB 209740).—This program performs the bookkeeping function for the Perspective Plot Program. It accepts three-dimensional coordinates of template points and corresponding point codes from available earthwork design programs that have this capability and converts them for input into the Highway Perspective Plot Program. It also insures that input data records are by station, that each record contains the same number of template points, and that point codes are properly assigned for generating connecting lines. The program accommodates up to 500 station records, a maximum of 97 points per cross section after template converion, which represents a maximum of six roadways. Refer to the previous report for a description of the methodology used in this program.

HIGHWAY PERSPECTIVE PLOT PROGRAM

Report FHWA–RD–72–6 (PB 208386).—This program accepts output from the Template Converter Program in the form of three-dimensional coordinates of template points and point codes. It performs a perspective transformation, removes those lines not visible to the viewer, and outputs data to the Plot Command Language Translator Program. Refer to report FHWA–RD–72–3 for a description of the methodology used in this program.

PLOT COMMAND LANGUAGE TRANSLATOR PROGRAM

Report FHWA–RD–72–4 (PB 210178).—This program accepts the standard plot format output from the Perspective Plot Program and "translates" it into a Calcomp Plotter tape. Refer to report FHWA–RD–72–3 for a description of the methodology used in this program.

RESECTIONING AND SCALING PROGRAM FOR PERSPECTIVE PLOTTING

Report FHWA–RD–72–7 (PB 208098).—This program computes the position, orientation, and focal length (scale) of oblique terrestrial photographs. This computation, known as resection, is based on the known X, Y, Z, coordinates of at least three points on the ground whose x and y coordinates have also been measured on a photograph.

This program is used in conjunction with the previously mentioned three computer programs that are capable of plotting perspective views of highways from design data.

The resection and scaling program provides the necessary data to the perspective plot programs for the production of photomontages, which consist of the graphical plot of the designed highway being superimposed on a photograph of the terrain through which the proposed highway is to be located. Refer to report FHWA–RD–72–3 for a description of the methodology used in this program.

Digest of Recent Research and Development Results

Reported by the Implementation Division, Office of Development

The items reported here have been condensed from highway research and development reports, predominantly of federally aided studied. Not necessarily endorsed or approved by the Federal Highway Administration, the items have been selected both for their relevancy to highway problems and for their potential for early effective application.

Each item is followed by source or reference information. Reports with an "NTIS" reference number are available in microfiche (microfilm) at 95 cents each or in paper facsimile at $3 each from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22151.

COSTS CUT BY AERIAL TRIANGULATION

Cost reductions are substantial where aerial triangulation is used in connection with photogrammetric mapping for highway location. These savings stem from reduced fieldwork for basic control surveying and elimination of supplemental control surveys. The Illinois Division of Highways has implemented the results of its recent research in which coordinate measurements obtained with the monocomparator are used in an aerial triangulation computer program employing the three photograph method. The report on this work was recently distributed nationally with copies to all State highway departments.

Analytic Aerial Triangulation for Highway Location and Design, Illinois Study No. IRH–804, Illinois Division of Highways. NTIS No. PB 183706.

FATIGUE STRENGTH OF WELDED STEEL BEAMS

Analysis and evaluation of recent research (NCHRP Report No. 102) shows that:

1. Stress range alone accounts for the variation in cycle life of structural steel.
2. The fatigue strength of a given welded detail is independent of the design strength of the steel.

The report suggests the need to reexamine current AASHO specifications with regard to the assumption that web-to-flange fillet welds can be neglected and the beam treated as a base metal for purposes of fatigue design. The report demonstrates that this assumption greatly overstates the fatigue strength of plain welded beams. The findings, based on constant-amplitude cycle loading tests, are considered highly reliable, and can be used immediately for improvement of specifications.

Effect of Weldments on the Fatigue Strength of Steel Beams, NCHRP Report No. 102. Available from the Highway Research Board, National Academy of Sciences, 2101 Constitution Avenue NW., Washington, D.C. 20418. Price $5.50 postpaid.

RAPID RETRIEVAL OF LIBRARY INFORMATION

A very practical rapid-retrieval system adaptable for use in any technical library was recently designed, installed, and tested as part of a research and evaluation project. Patterned after the Highway Research Information Service (HRIS) of the Highway Research Board, the system utilizes the HRIS list of authorized terms for indexing of stored documents. The study report discusses and describes the input, storage, searching, retrieval, and output operations of the system, which utilizes an optical coincidence retrieval method. This feasible, economical system satisfactorily solved a California local problem and is considered potentially usable in other States.

Document Retrieval in a Highway Research Library, January 1970, California Study No. G–1–1. California Department of Public Works, Division of Highways.

INCREASED FILL HEIGHTS OVER CONCRETE PIPE

Recent field test results indicate that large-diameter reinforced concrete pipe culverts, installed with specific attention to suitable construction techniques, can carry much higher fills than are normally specified.

An important aspect of suitable technique relates to construction of the pipe trench floor. The results justify California's current practice of placing all pipes in trenches excavated from preconstructed embankment material to a depth of at least two-thirds of the pipe diameter, and surrounding them with well-compacted granular backfill. The results also indicate that a 6-inch flat sand bedding produced structural behavior as satisfactory as that produced by a shaped bedding, and at significantly lower cost. The State is considering selected followup studies leading to revisions in California's fill height tables.

Structural Behavior of a Concrete Pipe Culvert. Report on HP&R Study No. R. & D. 4–71. Available from Department of Public Works, Division of Highways, Post Office 1499, Sacramento, Calif. 95807.

PRESTRESSED CONCRETE PAVEMENT FOR "TRANSPO 72"

The first full-scale section of prestressed concrete highway pavement built so far in the U.S. was placed at Dulles International Airport in the closing weeks of 1971. Six slabs ranging in length from 400 to 760 feet, and totaling approximately 3,200 feet of 24-foot-wide, 6-inch-thick prestressed concrete pavement, served as part of the traffic access facilities for the 1972 International Transportation Exposition (TRANSPO 72).

The prototype pavement is intended to test the practicality of new design and construction techniques, prior to any effort to generate interest among the States in constructing additional sections of prestressed pavements on major highway networks on an experimental basis. Color motion pictures depicting the pavement features and construction techniques are but one of the media being developed to provide information to contractors interested in bidding on subsequent projects. Its inherent potential for reducing maintenance problems associated with pavement joints in conventional pavements has stimulated considerable interest in prestressed concrete pavement. The prestressed pavement also makes more efficient use of the concrete and steel and thus reductions in thickness of concrete and amount of steel used are possible.

Placement of the prototype pavement for TRANSPO 72 was directed by a joint effort of FHWA personnel from the Office of Research and Region 15.

For further information, contact the Pavement Systems Group, Structures and Applied Mechanics Division, Office of Research, FHWA, Department of Transportation, Washington, D.C. 20590.

SIZES OF MOLD AND SOIL PARTICLE AFFECT DENSITY TESTS

Recent laboratory investigations indicate that test results for compacted soil density using constant energy input are affected by size of the mold, particle size, and moisture content. The compaction test materials were mostly weathered shale and unweathered dense blue shale. Previous field investigations had indicated that the field density obtained with these materials directly affected the swell factor, and that the degree of weathering also affected the percentage of swell.

Test results from 4-inch and 6-inch molds were compared with results obtained from a specially constructed 10-inch mold. It was found that mold size does not affect the density test results for natural fine-grained soils, but does affect reults for material having a 3-inch maximum particle size. Densities obtained with this particle size and the 10-inch mold were slightly greater—by approximately 3 pounds per cubic foot—for the hard blue shale material. The slight gain in accuracy obtained with the 10-inch mold is not sufficient to compensate for the disadvantages of using heavy equipment, larger sample size, and increased effort and time. However, in special situations requiring exact density of blocky material, the large mold may be valuable.

Effects of Particle Size and Mold Size on Density (Final Report). Available from South Dakota Department of Highways, Pierre, S. Dak. 57501.

BETTER PAVEMENT JOINT SYSTEMS

Transverse joint systems in rigid pavements often have problems for two significant reasons:

(1) At times faulting occurs where dowel bars are not used.
(2) Where dowels are used, the dowels frequently fail to function properly for the life of the pavement.

Such functional failures usually result because during placement the dowel bars were not properly alined or positioned or because they have corroded and become inoperative.

Current technology can contribute to solving the problems of joint systems, thus greatly improving the quality and performance of pavements with slight increase in costs and tremendous savings in subsequent maintenance. Such contributions include:

(1) Corrosion-resistant dowel bars are available and should be used.
(2) Automatic implanting of dowel bars with modern mechanical equipment can assure accurate placement and eliminate the expense of dowel supports.
(3) Accurate placement can lead to additional economy by permitting reduction of dowel lengths to 12 inches (at 1¼ inches diameter) instead of the 18 inches now commonly used. (See June 1958 issue of Public Roads magazine.)
(4) Shorter dowels can be used only where the weakened plane joints are accurately located at the midpoint of the dowel length. Available technology in metal detectors should assure the needed accuracy in location for sawing purposes.

The AASHO Road Test design for plain concrete pavement would benefit significantly with properly functioning joint systems, thus fostering wider application of this tested type of pavement in lieu of other more costly types.

For further information, contact the Pavement Systems Group, Structures and Applied Mechanics Division, Office of Research, FHWA, Department of Transportation, Washington, D.C. 20590.

PAVEMENT ASPHALT CONTENT BY NUCLEAR GAGE

Extensive tests and evaluations of a prototype nuclear gage specifically designed to provide, under field testing conditions, a sensitive measure of asphalt content of bituminous concrete, have given results that substantially agree with those from standard extraction tests. With semiskilled personnel, at 15 minutes per test the nuclear technique is four times more rapid than the conventional. The gage, which uses the neutron thermalization technique, was previously tested in the laboratory on controlled samples. Gage response was tested for waived gradation of aggregates as well as different types of aggregates, and for differences in hydrogen content by asphalt lots. Field test evaluation results show that when the effects of these variables are recognized and corrections allowed for in the calibration of the nuclear gage, the accuracy of the asphalt content determination is fully satisfactory.

Asphalt Content Studies by the Nuclear Method, Pennsylvania Study No. 64–15. NTIS No. PB 194332.

DRIVERS NEED HELP IN PASSING

A growing mass of data suggests the need for automated systems of driver remedial assistance in executing passing maneuvers on congested two-lane highways. A recent four-volume study is a first effort to examine the driver's discrimination and judgment problems associated with overtaking and passing with adverse visibility, including nighttime driving. The research revealed that drivers are poor judges of oncoming car speeds at night, and of overtaking and passing situations with adverse visibility. Variability in vehicle rear-end configuration, with particular reference to tail and stoplight position, size, and spacing, was found to be a major source of driver error in judging headway distance and closing rate at night. This research also resulted in the development and validation of an operational model (computer program) for the driver/vehicle/roadway system, useful in identifying possible solutions of specific problems in this area. Volume I of the report was recently distributed nationally to all State highway departments. Volumes II, III, and IV, dealing with documentary data and technical aspects of the research effort, received only limited distribution.

Overtaking and Passing Under Adverse Visibility Conditions, Volumes I–IV, by Franklin Institute, Biotechnology, Inc., and Systems Technology, Inc. NTIS numbers for the four volumes are PB's 184955, 184956, 184957, and 184958, respectively.

STRENGTH COEFFICIENTS FOR FLEXIBLE PAVEMENT BASE AND SUBBASE MATERIALS

Recently completed studies involving controlled strain static testing of various flexible pavement sections have developed strength coefficients for use in the AASHO Interim Design Method. For the conditions under which the tests were performed, the results show that the strength coefficients assigned to untreated base courses should be reduced with increasing thickness, while those assigned to treated bases should be increased as the layers are made thicker. Tests were conducted for numerous combinations of base and subbase materials, thickness of layers, and temperature and moisture levels.

This HP&R study report, titled *An Evaluation of the Relative Strength of Flexible Pavement Components*, is scheduled for distribution to State highway departments, FHWA field offices, and others interested in pavement design. The study was performed by Clemson University and sponsored by the South Carolina Highway Department, Columbia, S.C. 29202, from whom copies are available.

BITUMINOUS CONCRETE DENSITY BY NUCLEAR GAGE

Density determinations of bituminous concrete pavement using nuclear gages, evaluated by accuracy, reliability, and repeatability, have been judged satisfactory for construction control during compaction rolling. Since this nondestructive technique is four times faster than conventional density determinations, it contributes to improved quality and economy. Both back-scatter and air-gap gage techniques were evaluated as to feasibility of determining optimum rolling patterns for different mix designs, material characteristics, and rolling equipment. Air-gap tests were found to depend on only the top 1¾ inches of pavement material. Areas of lower density were found predominantly at the joints and pavement edges. The report's findings are based on the results of tests obtained on 70 projects over a 2-year period.

Evaluation of Bituminous Compaction Procedures Using Nuclear Gages, Pennsylvania Study No. 64–15. NTIS No. PB 194333.

EFFECTS OF STUDDED TIRES ON HIGHWAY SAFETY

Studded tires abrade roadway surfaces approximately 100 times as fast as nonstudded tires with surface application of sand and salt, according to a recent study by the Minnesota Department of Highways. (About 40 percent of Minnesota passenger cars were equipped with studded tires in the winter of 1969–70.)

Although studded tires improved stopping performance on glare ice by 10 to 30 percent and were therefore less involved in sliding accidents on icy roads, the study found no proof that such tires consistently reduce the severity of accidents on snowy or icy roads. It did find that surface wear attributable to studded tires caused premature loss of pavement markings, erosion of antiskid grooving, and formation of ruts which caused steering troubles and spray from accumulations of water. Consequently the report makes no definite evaluation of such tires with regard to safety.

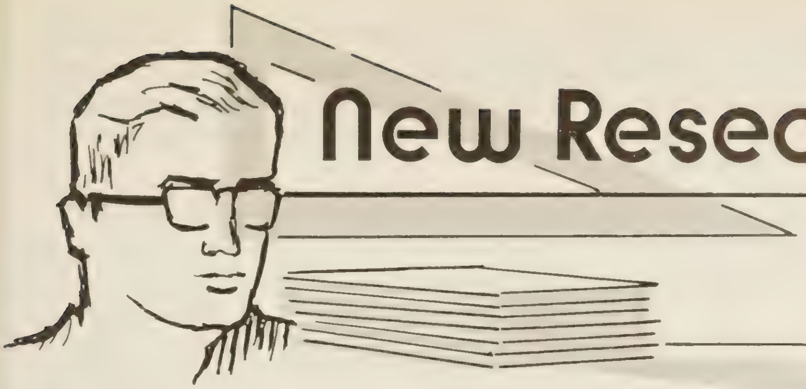
The State estimates that by 1980 the cost of repairing surfaces prematurely worn by studded tires will reach $12.6 million annually on the trunk highway system alone. Use of studded tires is now illegal for Minnesota motorists.

A Research Summary Report on the Effects of Studded Tires, March 1971. A Minnesota Highway Department study supported in part by the States of Illinois, Iowa, Michigan, New York, North Dakota, Pennsylvania, Utah, and Wisconsin. NTIS No. PB 204272.

IMPACT ATTENUATION WITH HYDRAULIC-PLASTIC CELL BARRIERS

A number of States have put into use experimental installations of various types of energy-absorbing impact attenuators. All are demonstrating varied but successful performance in preventing crash fatalities from vehicle impacts at gore areas, and several types are now considered operational. Tests and evaluations of one of these systems, involving water-plastic cells for the energy-absorbing function, have demonstrated versatility and economically attractive features. A computer model of the barrier's behavior shows good agreement with several full-scale collision tests. Barrier design modifications have resulted from this improved understanding of the mechanics of this type of impact attenuator. Computer-generated predictions of the behavior of this water-plastic unit indicates satisfactory performance across the range of the impact spectrum between 30 and 70 m.p.h. for vehicle weights of 2,000 to 6,000 pounds. The final report includes an operations manual pertaining to use of the barrier.

Development of a Hydraulic-Plastic Barrier for Impact-Energy Absorption. NTIS No. PB 192479.



New Research in Progress

Title. Producing Vegetation on Steep Slopes Concurrently With and Subsequent to Highway Construction.

Objective. To develop practices to more effectively produce temporary and permanent vegetation on disturbed soil areas both during and after construction.

Performing Organization. Virginia Polytechnic Institute, Blacksburg, Va.

Expected Completion Date. December 1975.

Title. Plan for Activities in Tunneling Research by FHWA.

Objective. A review of past and current tunneling research activities and the establishment of a relationship of previous and current work with present goals for improved technology.

Performing Organization. Datarex Corp., Beechhurst, N.Y.

Expected Completion Date. June 1973.

Title. Accommodating Utility Plant Within the Right-of-Way of Urban Streets and Highways.

Expected Completion Date. June 1973.

Objective. Within the framework of joint development and multiple use concepts, develop methods for locating utilities within street and highway right-of-ways considering safety, appearance, cost, service quality and reliability, efficiency of maintenance, and public convenience.

Performing Organization. American Public Works Association, Chicago, Ill.

Expected Completion Date. June 1973.

Title. Information and Control Systems for an Urban Freeway Corridor to Optimize Traffic Flow.

Objective. Ramp controls are being evaluated, frontage road signal controls are being implemented and corridor traffic strategies will be tested. A procedural manual will be developed to assist others in installing similar systems.

Performing Organization. Texas A. & M. Research Foundation, Dallas, Tex.

Expected Completion Date. June 1974.

Title. Freeway Lane Drops.

Objective. From field data determine effectiveness of existing main line lane drops from the standpoint of safety and traffic service. Determine effects of the significant parameters associated with various levels of safety and traffic service. Recommend configurations for lane drops based on the findings of objectives.

Performing Organization. Systems Development Corp., Santa Monica, Calif.

Expected Completion Date. February 1974.

Title. Methods for Evaluating Highway Safety Improvements.

Objective. Provide a detailed technique in the form of guidelines from which calculations can be made that will allow officials to judge the effectiveness of highway improvements in terms, not only of reduced accidents, but also of cost-benefit of such improvements.

Performing Organization. Operations Research Inc., Silver Spring, Md.

Expected Completion Date. July 1973.

Title. Functional Synthesis of Traffic Flow Models.

Objective. To identify traffic flow functional areas that need to be studied for freeways, and to synthesize the various traffic flow theories that have possible merit or impact to each functional area.

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

Expected Completion Date. February 1973.

Title. Speed Profiles and Time Delay at Rail-Highway Grade Crossings.

Objective. To collect and analyze speed and time delay empirical data for selected grade crossings having various protection types, train and motor vehicle volumes, and quadrant sight distances. These data will be used in economic analyses of alternative devices based on associated operating and delay costs.

Performing Organization. Biotechnology Inc., Falls Church, Va.

Expected Completion Date. May 1972.

Title. Elimination of Draper Strands in Prestressed Concrete Girders.

Objective. To study the behavior of blanketed prestressing strands to possibly eliminate draped strands in prestressed concrete girders.

Performing Organization. Tulane University, New Orleans, La.

Expected Completion Date. June 1973.

Title. Soil Stabilization for Erosion Control.

Objective. To investigate stabilizing agents and develop techniques to effect prompt erosion control on areas disturbed during highway construction. Tests will be conducted both in the laboratory and the field and will include such agents as high alumina cement, regulated set cement, and others which may be effective for that purpose.

Performing Organization. Purdue University, Lafayette, Ind.

Expected Completion Date. December 1974.

Title. Rest Area Waste Water Treatment and Disposal.

Objective. To analyze the problems associated with the treatment of waste-water from rest areas; to develop a strategy for satisfying the appropriate water quality standards; and investigate the practicality of developing a recycle system in rest areas with limited water supply.

Performing Organization. University of Illinois, Urbana, Ill.

Expected Completion Date. October 1974.

Title. Soil-Bridge Abutment Interaction.

Objective. Field instrumentation will be placed before and during construction. Movements and pressures will be measured at the bridge abutment, the piling, and in the adjacent soil. The data will be analyzed to develop a clear picture of the soil-structure interaction.

Performing Organization. Kentucky Department of Highways, Frankfort, Ky.

Expected Completion Date. June 1975.

Title. Systems Approach to Pavement Design-Implementation Phase.

Objective. (1) Finalize the SAMP–5 working system as a pavement design and management tool, (2) conduct a sensitivity analysis of SAMP–5, (3) pilot test SAMP–5, and revise the working system as necessary.

Performing Organization. Texas A. & M. Research Foundation, College Station, Tex.

Expected Completion Date. December 1973.

Title. Ridability Equipment Evaluation.

Objective. Compare various devices for measuring the roughness of pavements and determine their suitability for use by the maintenance department in evaluating the riding qualities of highway pavements.

Performing Organization. Maryland State Roads Commission, Baltimore, Md.

Expected Completion Date. March 1974.

Title. Implementation of Research Findings.

Objective. Special efforts to insure the results of research and development projects are brought into operating practice. Current effort is the preparation of additional training materials to implement results of the maintenance management project.

Performing Organization. Arkansas State Highway Department, Little Rock, Ark.

Expected Completion Date. June 1973.

Title. Implementation of Research Findings.

Objective. Special efforts to insure the results of research and development projects are brought into operating practice.

Performing Organization. Maryland State Roads Commission, Baltimore, Md.

Expected Completion Date. June 1973.

Title. Splicing of Precast Prestressed Concrete Piles.

Objective. To develop a method of field splicing that can develop the required strength and behavior of the pile. Full-scale piles will be used in field experimentation.

Performing Organization. Tulane University, New Orleans, La.

Expected Completion Date. September 1974.

Title. Field Evaluation of Sand-Drain Construction.

Objective. To evaluate and improve available methods for predicting rate of consolidation and strength increase obtained in foundation soil with and without sand drains.

Performing Organization. Ohio State University, Columbus, Ohio.

Expected Completion Date. April 1974.

Title. The Effect of Coatings on the Faying Surfaces of High Strength Bolted Joints.

Objective. To determine the behavior of friction type bolted joints with faying surfaces coated with rust inhibiting coatings.

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

Expected Completion Date. June 1974.

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 207838	Elastomeric Energy Absorber.
PB 207840	Test and Evaluation of Vehicle Arresting, Energy Absorbing, and Impact Attenuation Systems (Final Report).
PB 207841	Self-Stressed Sandwich Bridge Decks (Final Report).
PB 207856	Behavior of Axially Loaded Drilled Shafts in Beaumont Clay. Part 1—State of the Art.
PB 207857	Part 2—Site Investigation and Test Shaft Instrumentation.
PB 207858	Part 3—Field Tests.
PB 207859	Part 4—Design Inferences and Conclusions.
PB 207860	Part 5—Appendices.
PB 207934	Design of Slip Bases for Break-away Signs.
PB 207935	Backfilling Trench Excavations.
PB 207995	A Technique for Measuring the Displacement Vector Throughout the Body of a Pavement Structure Subjected to Cyclic Loading.
PB 207999	A Field Experiment with Mineral Filler—AASHO Road Test.
PB 208078	Soil Instrumentation for the I–95 Mit-MDPW Test Embankment.
PB 208140	Temperature Effects on Continuous Reinforced Concrete Bridge.
PB 208316	Field Investigation of a Prestressed Concrete Highway Bridge Located in Douglas County, Ill.
PB 208317	Bridge Girder Webs Subjected to Horizontal Loads.
PB 208318	Strength of Longitudinally Stiffened Plate Girders Under Combined Loads (Unsymmetrical Plate Girders).
PB 208338	A Method of Relating Flexible Pavement Performance to Design.
PB 208342	Development of an Analytical Approach to Highway Barrier Design and Evaluation.
PB 208350	Tensile Lap Splices, *Part 2:* Design Recommendations for Retaining Wall Splices and Large Bar Splices.
PB 208354	AASHO Correlation Study.
PB 208364	Effects of Pavement Surface Characteristics and Textures on Skid Resistance.
PB 208390	Study of Inservice Bridges Constructed with Prestressed Panel Subdecks.
PB 208391	Development of Length of Strands in Prestressed Panel Subdecks.
PB 208399	Shear and Anchorage Study of Reinforcement in Inverted T-Beam Bent Cap Girders.
PB 208408	Performance of Single and Double Sills for Steep Circular Culverts.
PB 208409	Precast Bridge Deck Study.
PB 208426	Soil Compaction Evaluation with Strain Measurements.
PB 208427	Appendix.
PB 208508	Development of a Rating System to Determine the Need for Resurfacing Pavements.
PB 208511	Faulting of Portland Cement Concrete Pavements.
PB 208512	An Evaluation of the CHLOE Profilometer and the Causes of Pavement Depreciation.
PB 208513	Wave Equation Prediction of Pile Bearing Capacity Compared with Field Test Results.
PB 208514	Evaluation and Prediction of the Tensile Properties of Asphalt-Treated Materials.
PB 208515	An Examination of Expansive Clay Problems in Texas.
PB 208517	Annual Report to Area III Research Advisory Committee on Important Pavement Research Needs, 1970–71.
PB 208518	Study of Variables Associated with Wheel Spin Down and Hydroplaning.
PB 208523	Flexible Pavement Performance in New York State.
PB 208569	Effects of Diaphragms in Bridges with Prestressed Concrete I-Section Girders.
PB 208570	Developing Pavement Feedback Data System.

MATERIALS

PB 207842	Pavement Cracking in Montana.
PB 207938	Photographic Techniques for Enhanced and Color-Balanced Aerial Testing Prints.
PB 207992	An Investigation of the Applicability of Acoustic Pulse Velocity Measurements to the Evaluation of the Quality of Concrete in Bridge Decks.
PB 207996	Control Strip Study (Interim Report).
PB 207997	Test Procedures for the Quality of Base and Subbase Materials.
PB 208000	Characterization of Asphalt Concrete and Cement-Treated Granular Base Course.
PB 208355	Development of a Programmed Freeze-Thaw Durability Testing Unit for Evaluating Pavement Materials.
PB 208404	Bulk Density Testing of Asphalt Base Course Material Research Report 70–7.
PB 208405	Paint Evaluation Program Manual.
PB 208407	Finite Element Program Feccon for Undrained Deformation Analyses of Granular Embankments on Soft Clay Foundations.
PB 208410	Binder Course Mix Uniformity Before Automation of Production.
PB 208528	Interim Report Covering 1970 Skid-Trailer Data.
PB 208531	Secondary Compression in Embankment Foundation.

TRAFFIC

PB 207861	System Analysis Methodology in Urban Traffic Control Systems—Phase II.
PB 207939	An Analysis of Traffic Operation on Westbound Lanes of I–70 Between Kingshighway Blvd. and Lucas-Hunt Rd. (Mark Twain Expressway Traffic Study).
PB 207991	An Automotive Telemetry System.
PB 207993	The Relationship of Vehicle Paths to Highway Curve Design.

PB 207994 Passing Performance Measurements Related to Sight Distance Design.

PB 208396 Application of Closed Circuit Television for Traffic Surveillance in Texas.

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PB 208386 Highway Perspective Plot Program.

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PB 208400 A Study of the Potential Applications of Completed Research.

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PB 207940 Problems in Establishing or Maintaining Vegetation on Roadsides.

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PB 208079 Annual Peak Discharges From Small Drainage Areas in Montana.

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PB 208516 Design Aspects and Performance Characteristics of Radial Flow Energy Dissipators.

PB 208522 Rest Area Wastewater Disposal.

RESEARCH IMPLEMENTATION

PB 207836 Livestock and Vehicular Underpasses (Final Report).

PB 207837 Livestock and Vehicular Underpasses Supplement to Final Report (98 Case Studies).

PB 207839 Investigation of Unbonded PC Overlays.

PB 207933 Slotted Corrugated Metal Pipe Drains (Final Report).

PB 207941 Skid Resistance of Mississippi Highways (Final Report).

PLANNING

PB 206090 Development and Testing of Synthetic Generation and Distribution Models for Urban Transportation Studies (Final).

PB 206481 Vehicle Classification Sampling Procedure for Continuous Court Locations—Preliminary Investigation (Final Report).

PB 206633 Experiences and Opinions of Residents Along Elevated, Depressed, and On-Grade Freeway Sections in Houston, Tex.

PB 207286 Determination of the Lanal Distribution of Truck Traffic on Freeway Facilities.

PB 207288 Red Oak and Corning (U.S. 34 Bypass).

PB 207304 Socio-Economic and Environmental Effects of Right-of-Way Acquisition.

PB 207998 Regional Economic Effects of Highway Investment—A Case Study of Interstate System (Final Report).

PB 208393 Documentation of the Travel Simulation Models Used in the Mass Transit Technical Planning Study in Milwaukee County.

PB 208394 Connecticut Master Transportation Plan—1972.

PB 208397 A Corridor Land Use Study: The Impact of an Interstate Highway on Land Values, Private Investment and Land Use in Southwestern Wyoming.

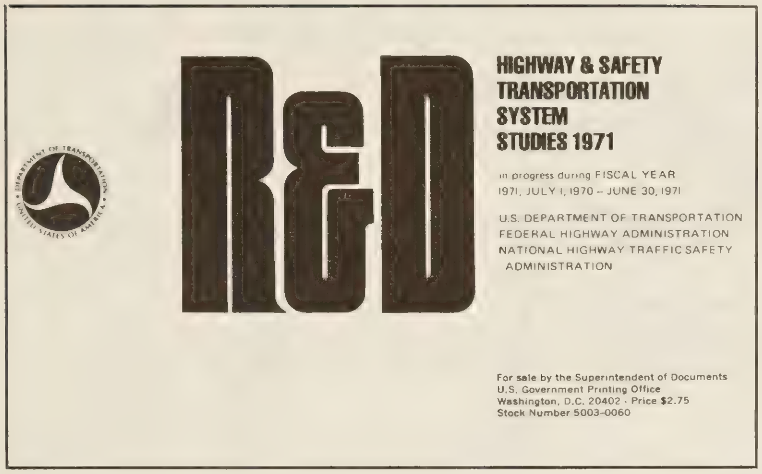
PB 208406 East-West Transitway Location.

PB 208425 The Impact of a New Interstate Highway on a Corridor: An Input-Output Analysis.

PB 208445 Milwaukee Central Area Transit Distribution.

PB 208994 General Criteria for Transitway Design.

NEW PUBLICATIONS



R&D

HIGHWAY & SAFETY TRANSPORTATION SYSTEM STUDIES 1971

in progress during FISCAL YEAR 1971, JULY 1, 1970 – JUNE 30, 1971

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

For sale by the Superintendent of Documents
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The information presented in *R & D Highway and Safety Transportation Studies 1971* pertains to research and development in highway transportation that is supported and aided by the Federal Highway Administration (FHWA), including the Bureau of Motor Carrier Safety (BMCS), and by the National Highway Traffic Safety Administration (NHTSA). NHTSA research and development activity is presented in two parts: (a) Contracts in progress during fiscal year 1971, and (b) all contracts awarded beginning with fiscal year 1967, the year of the agency's creation, through fiscal year 1971.

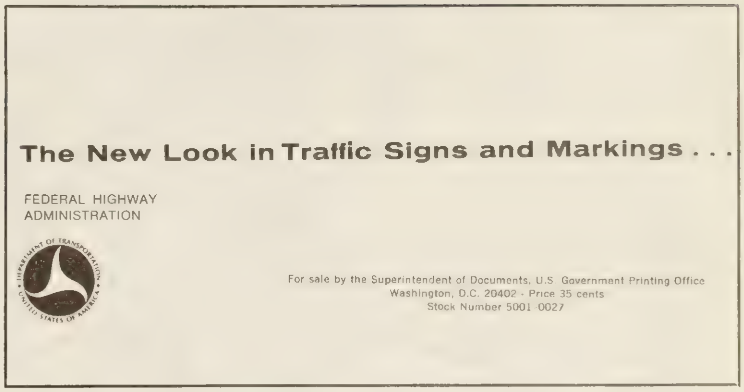
This publication is intended primarily for the information and guidance of Federal and State personnel concerned with highway-related research, particularly those in FHWA, NHTSA, and U.S. Department of Transportation (DOT), and those in State highway departments or departments of transportation. It will be useful also to other Federal and local government personnel, to highway-oriented and vehicle-oriented trade, professional, and research organizations, and to members of the general public interested in or concerned with research in highway transportation.

With full recognition being given to an effective and integrated highway system, programs are being developed by the Federal Highway Administration and the National Highway Traffic Safety Administration to:

- Stimulate increased performance, service, and reliability in the highway transportation system, so as to meet the requirements of the Nation for assured, convenient movement of passengers and property by the most efficient means consistent with public safety.

- Reduce the losses in deaths, injuries, and property damage sustained on the Nation's highways, by developing and applying effective safety performance standards for motor vehicles, drivers, and highway plant, including provision (along with other government agencies) for emergency medical response systems.

- Accentuate, in present and future highway systems, the social, economic, and esthetic contributions which will make the system more harmonious with its physical and cultural environments, and will improve the overall quality of living.



The New Look in Traffic Signs and Markings . . .

FEDERAL HIGHWAY ADMINISTRATION

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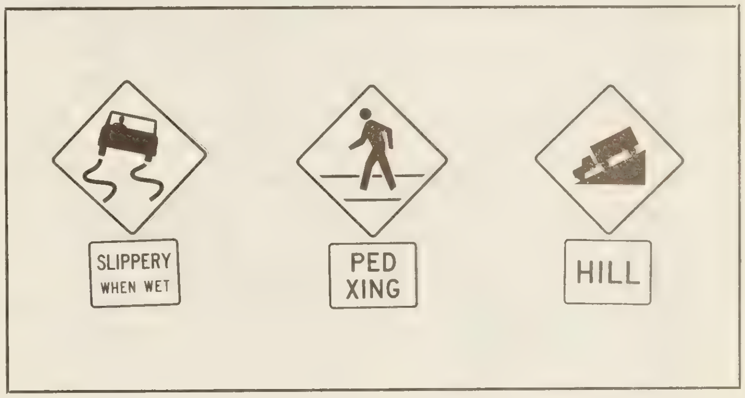


The New Look in Traffic Signs and Markings is a booklet to help acquaint motorists with the widespread changes in traffic signs, markings, and signals. In the next few years, these changes will affect every American motorist and pedestrian. In fact, some of the new signs already are appearing on Federal-aid highways throughout the country.

The United States is moving toward an international-type system of traffic control devices, which emphasizes pictures and symbolic signs rather than written messages.

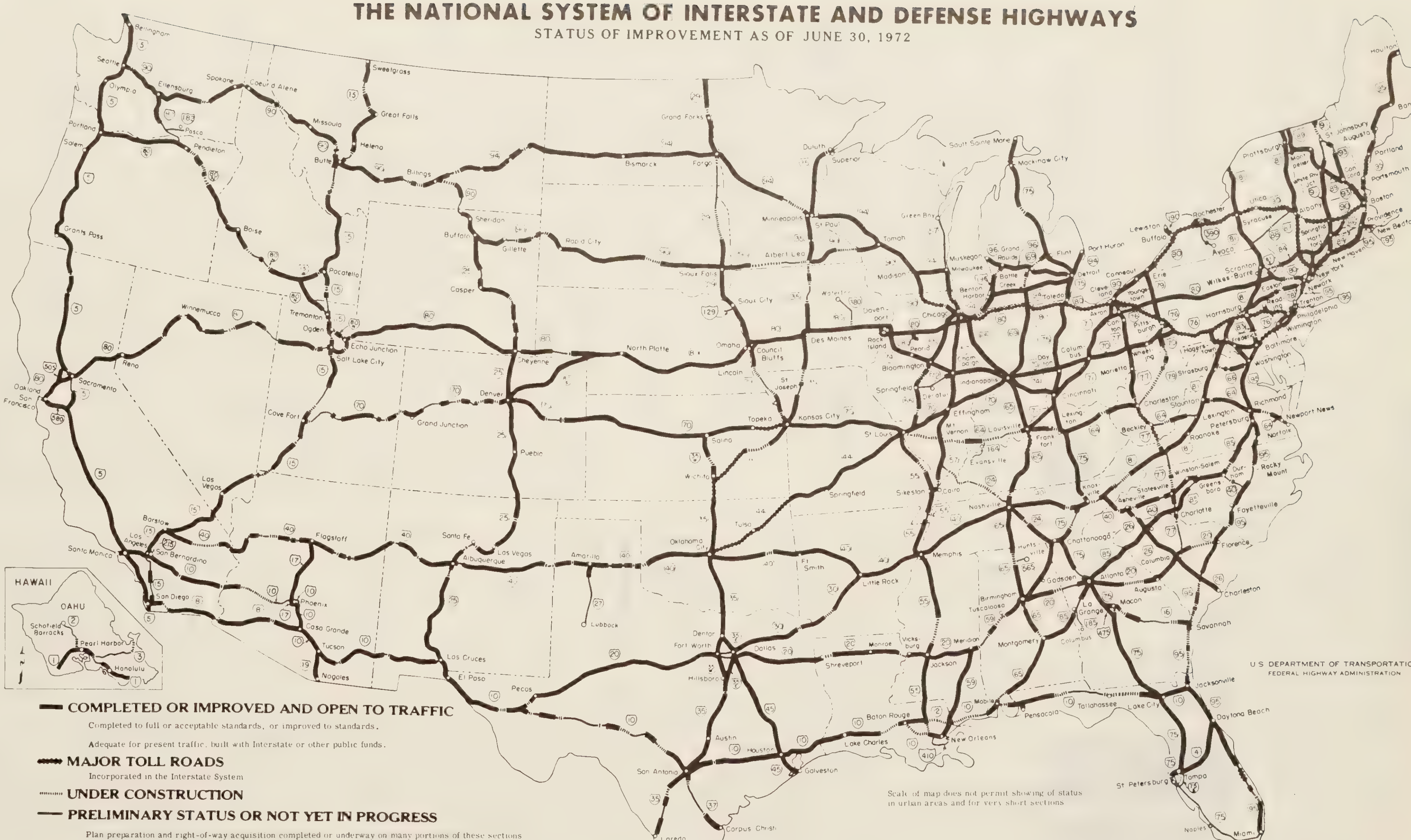
Symbolic signs are not entirely new; the curve and crossroad symbols have been used for many years. Symbols have several advantages over word messages. They provide almost instant communication with the driver, since they can be understood at a glance without having to be read. Also, they overcome language barriers. This is important in view of the growth of international travel. Familiarity with symbolic signs will help Americans traveling abroad, as well as foreign visitors traveling in the United States.

Some of the present word signs will remain in use. For example, stop and speed limit signs contain easily understood messages and have proved effective in the past.

Changes will be gradual. States and local communities have a target date of 1973 to implement pavement marking requirements; 1975 for signs, and 1977 for signals. As the new signs are introduced, companion word messages also will be used until the public becomes accustomed to the new system.

THE NATIONAL SYSTEM OF INTERSTATE AND DEFENSE HIGHWAYS

STATUS OF IMPROVEMENT AS OF JUNE 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.

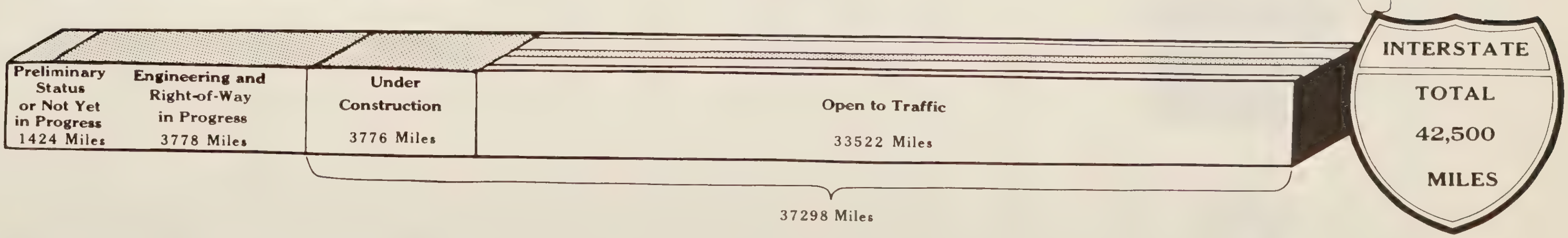
MAJOR TOLL ROADS

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



U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 472-822

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.

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.

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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.

Role of Economic Studies in Urban Transportation Planning (1969). 65 cents.

(*Continued on reverse side*)

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 Land Use Coding Manual (1965). 50 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.
- Vol. IV—Typical Continuous Bridges (1969). $1.50.
- Vol. V—Typical Pedestrian Bridges (1962). $1.75.

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

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.

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.