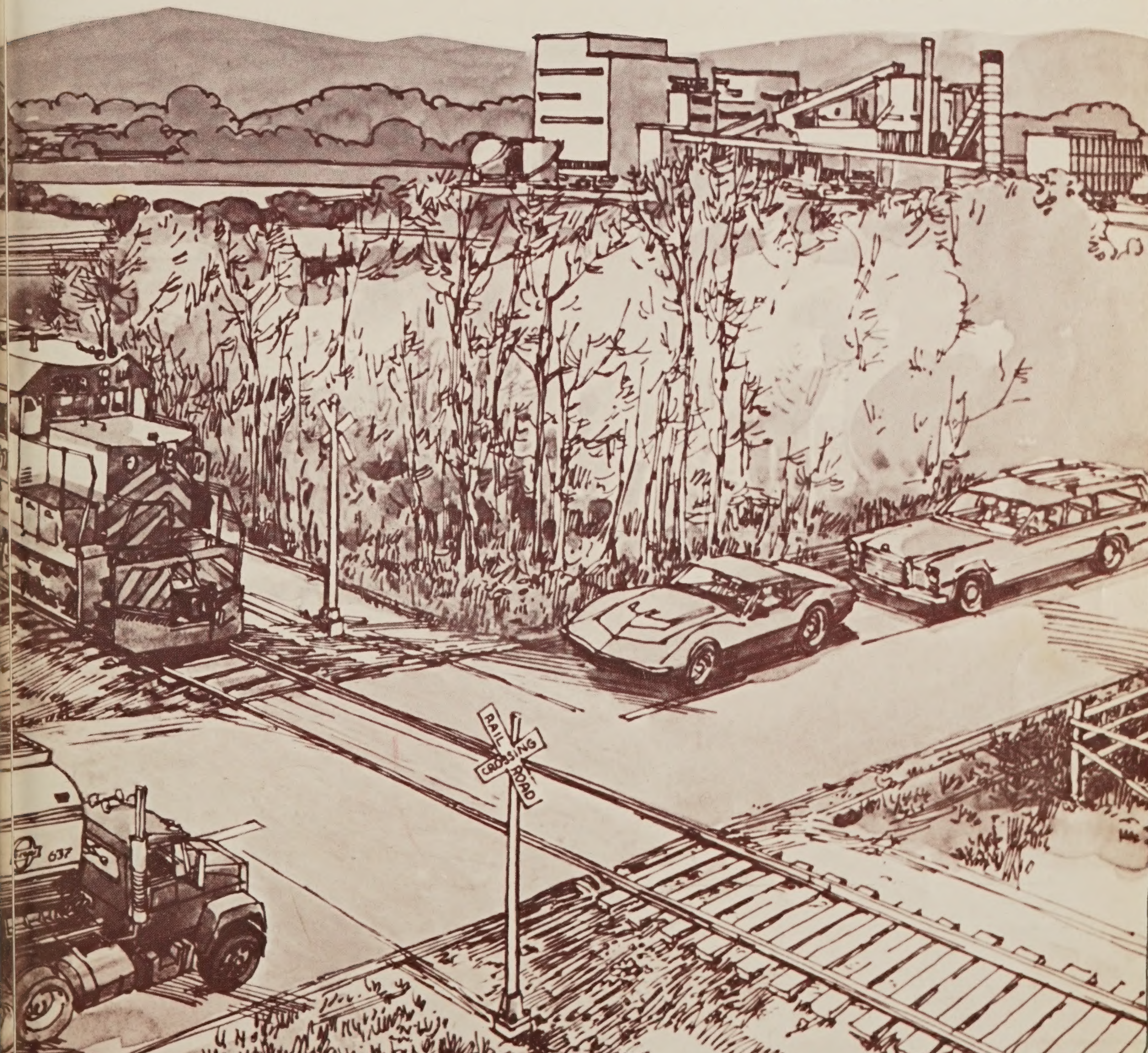
public roads

March 1977 Vol. 40/No. 4



A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT

U.S. Department of Transportation Federal Highway Administration

public roads

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT

March 1977 Vol. 40/No. 4

COVER:
Artist's concept of passive signing in use at railroad grade crossings. (Published with permission of WABCO—Union Switch & Signal Division.)

IN THIS ISSUE

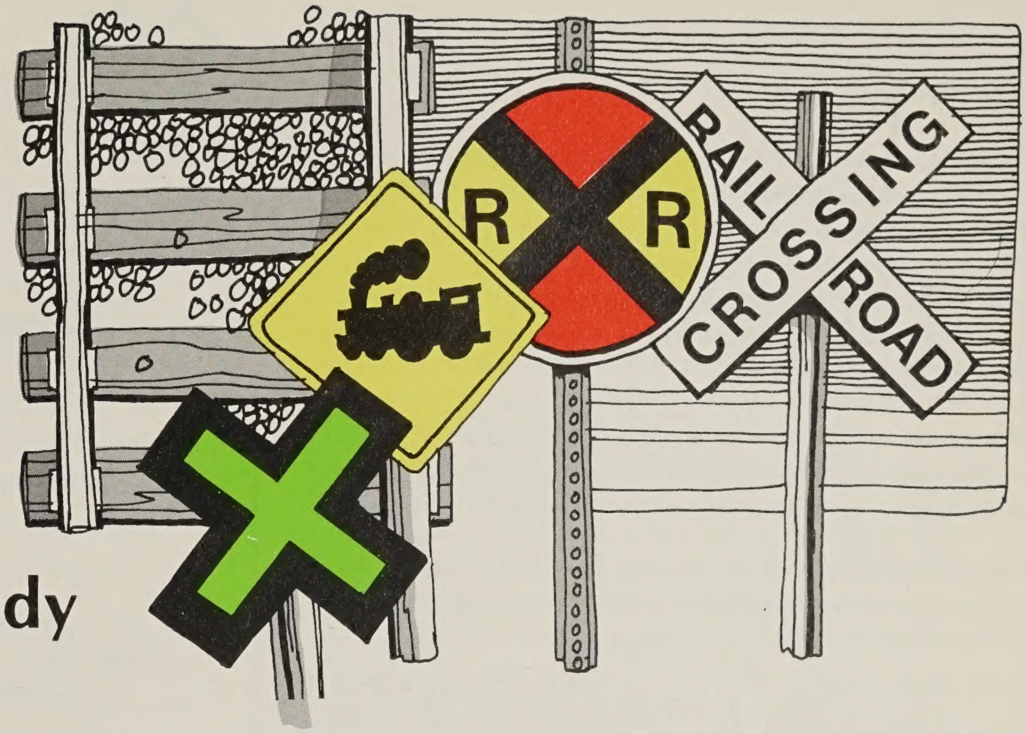
Articles

Departments

Address changes (send both old and new), requests for removal, and inquiries concerning the *FREE* mailing list should be directed to:
Public Roads Magazine, HDV–14
Federal Highway Administration
Washington, D.C. 20590

Public Roads, A Journal of Highway Research and Development, is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, at $7.60 per year ($1.90 additional for foreign mailing) or $1.90 per single copy. Subscriptions are available for 1-year periods. Free distribution is limited to public officials actually engaged in planning or constructing highways and to instructors of highway engineering. There are no vacancies in the free list at present.

The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through March 31, 1981.



Railroad Grade Crossing Passive Signing Study

by Janet Coleman, Joseph S. Koziol, Jr., and Peter H. Mengert

Most railroad grade crossings in the United States have passive warning signs only. A study is now underway to develop improved signing for use at grade crossings. This study is jointly funded by 25 States, the Federal Railroad Administration, and the Federal Highway Administration. This article, a condensation of a report,[1] describes the seven signing systems (combination of an at-crossing sign and advance warning signs) tested in two States during Phase 1 of the study, the types of data collected, the results of Phase 1, and the final three signing systems to be tested nationwide in Phase 2 of the study.

Introduction

There are about 223,000 public railroad-highway grade crossings in the United States. Of these public railroad-highway grade crossings, 48,000 have **active** types of warning which provide the driver with a positive indication of the approach of a train. The remaining 175,000 public crossings have some type of **passive** warning. Static signs and markings constitute the usual form of passive warning. These inform the motorist of the existence and location of a crossing, but it is the driver's responsibility to determine independently whether a train is approaching and whether it is safe to cross. With more than three-fourths of the Nation's public grade crossings equipped only with static signs, it is most important for the signs on the approach and at the crossing to be effective. Furthermore, at the 70,000 or more crossings in the lowest classification for both railroad and highway traffic volumes—that is, two or fewer trains per day and 500 or fewer vehicles per day—economic justification for other than minimum type of warning, such as static signs, does not appear possible. The majority of railroad-highway grade crossings will continue to have only signs and markings which provide passive warning to drivers to proceed with caution at railroad-highway grade crossings.

To determine which signs would most effectively warn drivers of the hazards at railroad-highway grade crossings, a study was initiated to evaluate the effectiveness of seven new passive signing systems. The study is jointly funded by 25 States, the Federal Railroad Administration, and the Federal Highway Administration. The study was divided into two phases. This article covers the results of the first phase of the study.

The purpose of Phase 1 was to determine, on a limited scale, if any of the new signs were more effective than the existing signs. Phase 1 also was used to determine the important variables for the study. The purpose of Phase 2 is to test and verify, nationwide, the most effective signs as determined in Phase 1. In Phase 1, five grade crossing sites in Ohio and one in Maine were used. Data were collected at each site for the existing standard signs and three experimental systems so that relative improvements of the new signs could be determined. The five sites in Ohio were selected with an attempt to minimize site-to-site effects such as variations in average daily traffic, numbers of trains, and sight distance restrictions. The Ohio sites served as the primary sites from which major findings of sign effectiveness were determined. The site in Maine served as a control in the total experimentation providing information on novelty (learning effect) and seasonal, directional, and weather effects. Manual and electronic data, as discussed below, were collected at each test site.

[1] "Railroad Grade Crossing Passive Signing Study," by Joseph S. Koziol, Jr., and Peter H. Mengert, *Transportation Systems Center, U.S. Department of Transportation*, Cambridge, Mass., December 1976.

Signs

Seven new passive sign configurations plus the base (standard) configuration were evaluated during Phase 1 (figs. 1 and 2). The base configuration included, on each side of the crossing, a standard white crossbuck with the "Railroad Crossing" legend and a standard advance warning sign consisting of a reflectorized yellow circular sign with a black "X" and the letters "RR."

The new systems evaluated were made from combining at-crossing crossbucks and advance warning signs which are shown in figures 1 and 2. These systems were as follows:

- Sign Configuration 1 included the standard yellow and black advance warning sign and a yellow crossbuck at-crossing sign with a black border.
- Sign Configuration 2 was the same as Sign Configuration 1 except both signs were bright yellow-green instead of yellow.
- Sign Configuration 3 consisted of the red and white International Swiss Crossbuck (or the St. Andrews Cross) as the at-crossing sign and a circular advance warning sign with the same type of cross and letters "RR" on a yellow background.
- Sign Configuration 4 (the Texas system) consisted of the Texas at-crossing sign with the top and bottom quadrants red and the side quadrants yellow, and the standard advance warning sign with the top and bottom quadrants changed to red.
- Sign Configuration 5 consisted of a yellow crossbuck with black border at-crossing sign and a round yellow train symbol advance warning sign.
- Sign Configuration 6 was the same as Sign Configuration 5 except the advance warning sign was a yellow diamond-shaped sign.
- Sign Configuration 7 was the same as Sign Configuration 1 with the addition of an auxiliary sign, which was diamond shaped, with the legend "LOOK FOR TRAIN" in black on a yellow background. The auxiliary sign was located midway between the advance and at-crossing signs.

Only the base and Texas at-crossing signs bore the legend "RAILROAD CROSSING." All other at-crossing signs had no legend. The advance warning signs were all 36 in (910 mm) across and the crossbucks were all 48 in (1,220 mm) in diagonal length.

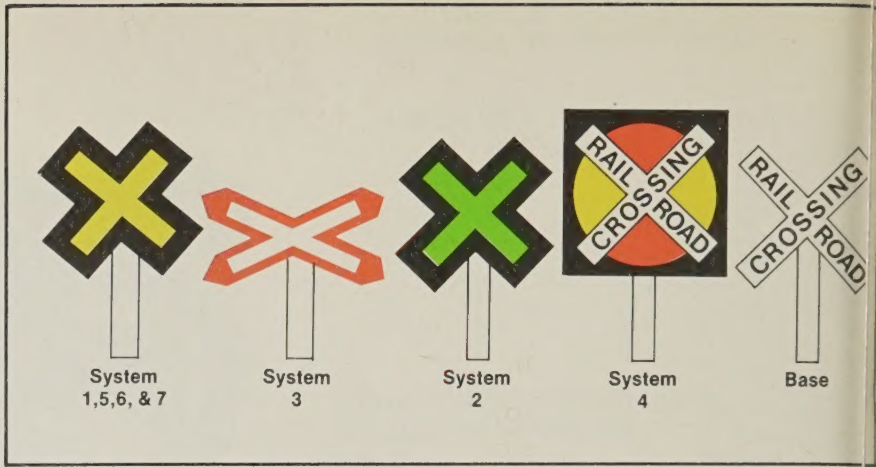


Figure 1.—Crossbucks tested in Phase 1.

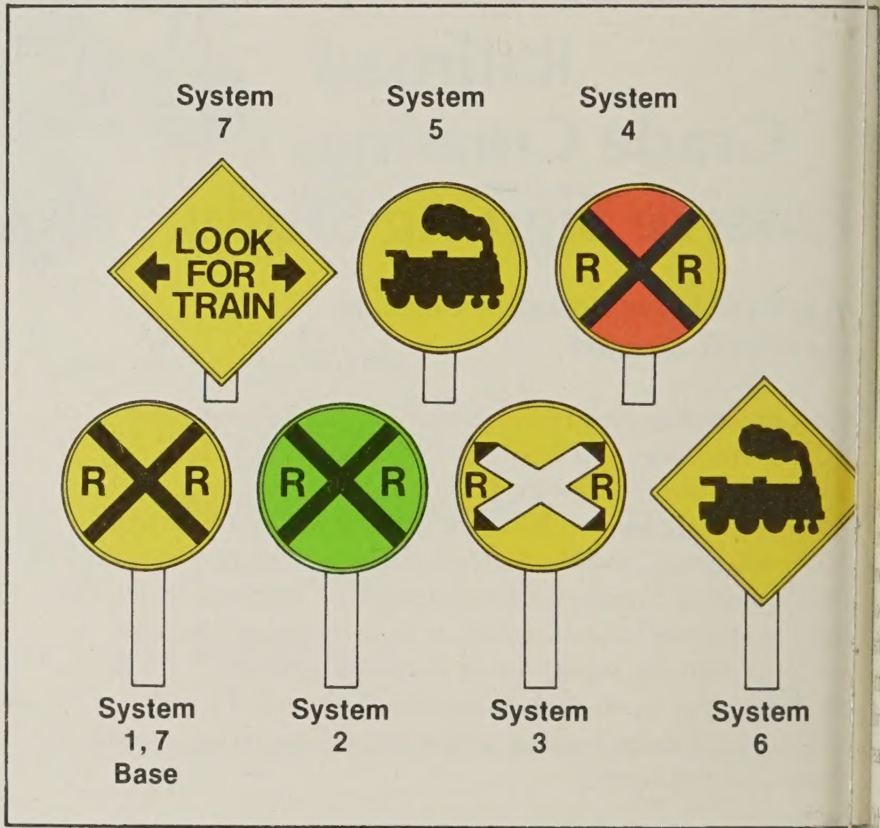


Figure 2.—Advance warning signs tested in Phase 1.

Data Collection

During the data collection, both dependent and independent variables were measured or recorded manually for each sampled vehicle as it traversed the test area.

The *independent variables*, those that essentially remained constant for each sampled vehicle, included:

- Site location (five in Ohio, one in Maine).
- Time of day (day, night).
- Vehicle type (car, other).
- License plate (in-State, out-of-State).
- Driver (male, female).
- Passenger in vehicle (yes, no).
- Required stop vehicle (yes, no). Required stop vehicles are (1) motor vehicles carrying passengers for hire, (2) school

buses carrying any school child, and (3) vehicles carrying explosive or flammable materials.

- Speed greater than 45 mph (72 km/h) on entrance to data collection zone (yes, no).
- Train expected (yes, no). A train is expected for a given vehicle if it arrives at the crossing within 1 hour of that vehicle.
- Weather (good, bad). Bad weather for purposes of the reported experiment was defined as rain, snow, fog, or wet roadway conditions.

Night data were not collected at the Maine site and bad weather data were not collected at the Ohio sites.

The *dependent variables* recorded were head movement, speed profile, and time headway. Head movements were collected manually while speed profiles and headway were collected electronically. For the reported experiment, head movements, as observed by a manual data collector, were defined as when an observed driver moved his head to look up or down the track within the measurement zone—approximately 600 ft (183 m) from the crossing up to the crossing. Data collectors were instructed to indicate head movement only when they were certain that the driver looked for a train. This was an important measure of effectiveness which provided not only an indication of the attentiveness and safety orientation of the driver, but also a direct and positive indication of the driver seeing and reacting to a particular sign configuration.

Other major measures of effectiveness used, which were derived from the speed profile data, were:

- Total Speed Reduction, which was defined as maximum speed minus minimum speed (based on sensed speeds) in the measurement zone when maximum speed occurs first; zero otherwise. This measure provided an indication of whether or not the driver reacted to the sign configuration by slowing down. This measure, together with the next measure, provided a concise representation of the vehicles' speed profile. In general, large values of total speed reduction implied more sign effectiveness.
- Speed Near Crossing, which was defined as the average speed (based on the sensed speeds) of the vehicle within 200 ft (61 m) of the crossing on the approach side. This measure in itself provided information on safety since speed is related to safety. Since advance warning signs were generally located approximately 300 to 600 ft (91 to 183 m) from the crossing, reaction to the advance warning signs could be expected to occur before the driver was near the crossing. In general, smaller values of this measure implied more sign effectiveness.

Ohio

Electronic and manual data were collected on only one side of a crossing at the Ohio sites. The electronic data, which provided speed profile information, were obtained using a Kinemetrics Data Acquisition system housed in a mobile van. The van was parked beside the road about 100 to 200 ft (30 to 61 m) from a crossing. Although visible to the passing motorists, it did not seem to affect the driver's response to the various sign configurations. It appeared to be a recreational vehicle due to the rural setting, and most of the passing motorists paid little or no attention to it.

The measurement zone for each test site in Ohio was approximately 600 ft (183 m), that is, from the first sensor located approximately 600 ft (183 m) from the crossing up to the crossing. The sensors (cables) were laid across one lane of the roadway on the approach side of a crossing and were activated by each axle of each vehicle. The activation times of each sensor were stored on magnetic tape located in the van for subsequent data reduction and analysis. The sensors were taped to the roadway using camouflage tape and thus were very difficult for a passing motorist to detect.

Manual data were collected by an observer located in the van. The manual data consisted of the time a vehicle crossed the crossing, vehicle type, passenger/no passenger, in-State/out-of-State vehicle, male/female driver, driver looked for train/did not look, vehicle stopped at crossing/did not stop, and the time a train crossed the crossing.

Data were collected for 2 days at each site, including 4 hours of night data. Data during the daylight hours were fairly equally distributed between morning and afternoon hours in order to minimize time-of-day effects. Data collection at night (no manual data) did not begin until 1/2 hour after sunset.

Maine

The Maine railroad grade crossing site is located on the Maine Facility, which is a 15-mi (24 km) stretch of instrumented highway along U.S. Route 2 in northern Maine between Newport and Canaan. This facility has the capability of detecting vehicles, tracking their position as they travel along sections of the electronically instrumented two-lane road, and storing the collected vehicle information on magnetic tape for subsequent off-line data reduction. The measurement zones for the railroad crossing experiment were 800 and 1,000 ft (244 and 305 m) long, for westbound and eastbound traffic respectively. The electronic system provided link speeds between successive 200 ft (61 m) spaced sensors within the measurement zones. Manual data, similar to those collected in Ohio, were collected at the Maine site. Both electronic and manual data were also collected at the Maine site during periods of inclement weather to determine its effect on driver response to the new sign configurations.

Study Findings

To determine which experimental signing systems were the best after accounting for special site effects, an analysis of variance technique was used to study the Ohio data. The data for the base (standard signing) were set equal to zero. The data for each new signing system are shown as mean estimates of effectiveness relative to the base. The relative mean effect estimates for the Ohio data are shown in table 1.

Table 1.—Ohio analysis results. Relative mean effect estimates.

Sign systems	Head movement	Speed reduction	Speed near crossing
	Percent	*Mph*	*Mph*
0 (Base)	0.0	0.0	0.0
1	20.1	1.1	-0.3
2	19.5	0.5	-0.8
3	18.6	0.6	0.2
4	26.4	1.4	1.9
5	9.2	-2.1	0.8
6	16.8	0.5	0.5
7	20.4	0.8	-0.5

1 mph=1.6 km/h

The only major significant finding of Phase 1 of the study was that the new signs in Ohio averaged an increment of 19 percent more head movement than the base sign (99 percent significant). The Texas signing system and the look-for-train signing system showed the most effectiveness, but not significantly, with respect to the other new signs.

The Maine data appeared to be strongly influenced by a seasonal trend and other extraneous effects making a determination of the most effective sign(s) quite difficult. In general, the Maine data did not show the strong indications of effectiveness (in terms of head movement) for all signs as was the case for the Ohio data. Also, there were only a few indications of effectiveness (not significant) for the Texas and look-for-train signs.

The following groups of drivers showed significantly more head movement, more speed reduction, and less speed near the crossing than their counterparts:

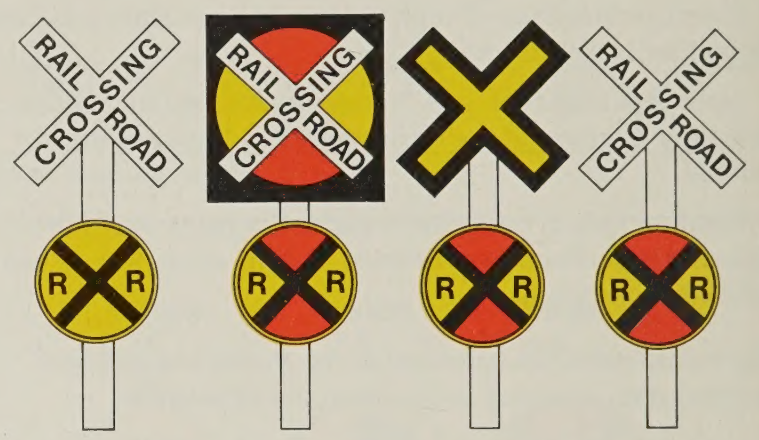


Figure 3.—Crossbucks and advance warning signs to be tested in Phase 2.

- Required stop vehicles.
- Female drivers.
- Drivers with passengers.
- Out-of-State drivers.

As could be expected, vehicles that approached the crossing at speeds less than 45 mph (72 km/h) showed more head movement, less speed reduction, and less speed near the crossing than vehicles that approached the crossing at speeds greater than 45 mph (72 km/h).

Based upon the preceding results, a study advisory committee—composed of representatives from the 25 participating States, the Federal Railroad Administration, the Federal Highway Administration, and the Association of American Railroads—selected three signing systems plus the current standard system (fig. 3) for further study in Phase 2 of the reported research. These new systems are:

- The Texas at-crossing sign with the Texas advance warning sign.
- The yellow crossbuck at-crossing sign with the Texas advance warning sign.
- The standard white crossbuck with black lettering at-crossing sign with the Texas advance warning sign.

Field data collection at 18 sites in 14 States for Phase 2 of the Railroad Grade Crossing Passive Signing Study began in April 1976 and ended in December 1976. Study results are expected to be available by April 1977.

Highway Ice Detection

by Charles Philip Brinkman

Introduction

Ordinarily, it is easy for a pedestrian to detect ice—he sees it. An unsuspecting motorist may not be so fortunate. Highway departments have long sought a reliable ice detector to alert highway crews and motorists of the danger ahead. Such a warning device may be an answer to the increasing numbers of liability suits State highway departments are facing.

Experiments have shown that motorists respond to conspicuous, activated signs (*1, 2, 3*)[1] with explicit warnings. A recent study (*1*) revealed that average speed reduction when such a sign was activated under general icing conditions on an interstate highway was about 7 mph (11 km/h). It was higher during localized icing conditions. This motorist response shows that a reliable ice warning system can be beneficial for potentially dangerous situations such as icy bridges.

Yearly benefits of activated signs for a particular bridge could range from a few hundred dollars to about $100,000. Unfortunately, detecting ice on roadways and activating warning signs by an electrical or mechanical device is no simple matter.

[1]Italic numbers in parentheses identify the references on page 148.

Requirements for Ice Detection

Ice warning signs must give an accurate indication of the ice condition on the road surface. They must maintain motorist confidence by not creating false alarms, and must reflect only the surface roadway conditions rather than nearby conditions. These nearby conditions may be very different because of (1) differing temperatures in the roadway and the air (for instance, bridge deck air temperature differentials caused by a net heat loss due to radiation), (2) lowering of the freezing point by residual deicing chemicals, and (3) effects of traffic.

Methods of Detection

The most obvious way to detect a wet or icy condition is to measure some physical property which is different for a dry, wet, or icy pavement. It is often necessary to measure at least two properties to differentiate among these three conditions. Some of the properties used are electrical conductivity, electrical capacitance, latent heat of fusion, air and pavement temperature, humidity, vibrational frequency, and spectral temperature.

An alternative to ice detection is ice prediction based on measurements of weather characteristics such as air temperature and relative humidity. Attempts to develop a predictive model, however, have been unsuccessful (*4*) because weather changes can occur suddenly, conditions can hover between freezing and nonfreezing, and the influence of deicing chemicals and traffic is not easily accounted for.

The most typical ice detector for highway use is a conductivity/temperature device. Moisture is detected by an increase in conductivity on a heated probe maintained above 0° C. Ice is differentiated by noting a much greater conductivity of the heated probe compared to the unheated probe when the pavement temperature is below 0° C. The more primitive conductivity devices are unable to account for the presence of deicing chemicals. The problem is that the conductivity for solutions with a high salinity resembles the salt precipitate deposited on the surface of the detector head when the solution freezes. (*5*)

Perhaps more promising is a device which detects water or ice on the probe by noting an increase in electrical capacitance as compared to air alone. This device discriminates between ice and water with a conductivity probe incorporated in the same sensor head plate that measures capacitance. Temperature measurements are used only as a control, that is, ice is never indicated when the pavement temperature is above 0° C. The system logic accounts for the effect of deicing chemicals by noting the increased electrical conductivity of the electrolyte.

Another device detects ice by applying a thermal pulse to a witness plate and noting a delay in the temperature rise due to the latent heat of fusion (the amount of heat required to change 1 gram [g] of a substance from a solid to liquid with no temperature change). To convert 1 g of ice to water with no temperature change requires 335 joules (J), while to raise 1 g of water 1° C requires only 4.19 J. The presence of ice will be indicated by a delay in the expected temperature rise. This device is not affected by deicing chemicals. However, it melts ice and snow in the process of detection. This melting makes subsequent examinations inaccurate since there may not be ice or snow on the device even though there may be some elsewhere on the pavement.

Another ice detector works by detecting a decrease in the vibrational frequency of a cone. This decrease is caused by the increase in the mass of the cone which occurs when ice adheres to its surface. This device was developed for detecting ice on antennas. Because it cannot be installed in the roadway surface, it cannot accurately reflect actual pavement conditions. Therefore, it is inappropriate for operating ice warning signs.

Research Results

A recent Federal Highway Administration (FHWA) evaluation of ice detectors' performance in the highway environment showed they are not sufficiently advanced to be useful for operating ice warning signs on bridges. The devices tested, representative of those commercially available, failed to detect some icing events, missed parts of others, and had numerous false alarms. Overall results of the evaluation were disappointing.

Two research studies primarily contributed to these findings. In one study (*2*) the performance of three ice and snow detection systems was evaluated to determine their utility in conjunction with a motorist warning system.

The ice detectors use three different detection methods:

1. Conductivity/temperature.
2. Electrical capacitance/conductivity.
3. Latent heat of fusion.

Throughout 2 years of testing (in both the laboratory and on a highway bridge) the devices experienced electrical and mechanical failures and required modification, recalibration, and adjustment. Based on these results, none of the detectors tested was sufficiently reliable or accurate to operate a motorist warning system.

First Winter Evaluation

Specific problems during the first winter of testing included a breakdown of the insulation on the heater wires in a deck sensor head, faulty printed circuit boards in a controller unit, a defective in-line amplifier, and a damaged deck sensor head.

A conductivity/temperature device showed the best overall performance for the first winter. During April, the device went to either "ice" or "alert" status 12 times. Three were considered false alarms and nine proper responses. There were no "missed" events. The three false alarms were in the frost prediction mode. Several times, unexplainably, the reaction for those events to which the device responded correctly came up to 1 hour after the onset of the event.

The capacitance/conductivity devices performed erratically. During April the functioning unit went to "alert" or "ice" status 11 times and only 2 of these times could be associated with an event. Alarms on five confirmed events were missed.

Throughout April, the latent heat of fusion devices cycled between clear and ice almost continuously, apparently without regard to the actual weather conditions.

A summer laboratory test program was conducted on the units to ascertain whether any of the three systems could be operationally improved by simple design changes or improved calibration procedures. It was concluded that, although design improvements could be made, the basic limitation was the difficulty of detecting the full range of hazardous conditions from the parameters measured.

Second Winter Evaluation

After calibration, during the second winter the operation of the detectors was monitored 24 hours per day between March 11 and April 7, 1975. During this 28-day period there were 14 hazardous bridge events lasting from 1 hour and 21 minutes to 46 hours and 57 minutes. These events resulted primarily from snow, slush, or ice existing on all or a portion of the bridge deck surface—conditions which could be considered potentially hazardous. There was one frost event and one "black ice" event. Black ice derives its name from the dark, wet appearance that ice sometimes gives an asphalt pavement, particularly under vehicle headlights. This black ice resulted from a light snowfall occurring on the cooling but nonfreezing roadway surface. The melted snow refroze before the surface could dry.

During this period, the performance of all the devices was even more disappointing. Both of the conductivity/temperature devices failed. The latent heat of fusion devices would have activated the motorist warning system correctly for about 2 hours out of 173 hours of actual sign operation over the 14 hazardous bridge events. The manufacturer recognized that the heater power applied to the three heads in successive 30-minute intervals is insufficient to melt any appreciable accumulation of ice or snow on the sensor head. The system was designed to detect frost, but a more powerful heater might make it capable of detecting ice conditions.

The functioning capacitance/conductivity device is the most promising. Although highly superior to the performance of the other sensor systems, only three events were covered more than 90 percent of the total eve . time and one of these produced a 6-hour-13-minute event out of an actual 1-hour-29-minute event time. Five of the 14 actual events were never detected by the sensor.

The other study monitored the performance of two commercial ice detectors (both conductivity devices) on a highway bridge for three winter seasons. The study concluded that their reliability as motorist warning devices was unsatisfactory because of "a difference between icing conditions apparent to a motoring observer and the actual conditions on the surface of the deck."

For instance, snow may accumulate over a thin layer of water. Depending upon the physical parameters measured and the system logic, an ice detector may not recognize this condition as being icy. As far as the motorist is concerned, the system merely is incorrect. A "dry" snow may pose problems for a detector that differentiates between clear and water or ice by measuring electrical capacitance because the dielectric constants for "dry" snow and air are similar. If the sensitivity of the detector were increased, however, more false alarms would likely result.

Area Detectors

All of the previously discussed ice detection methods detect ice only at the small area examined by the detector. Some types of icing events are anything but uniform. Shaded areas, ice piled from snow removal operations, a chunk of ice dropped by a passing car, refreezing of melt water, and in the case of bridge decks, nonuniform heating and cooling of the deck, can play havoc with point detectors. The specific location of the sensor head becomes a critical variable in whether the ice will be detected. And the optimal location will vary not only with the specific site but also with such things as time of day and year and weather conditions. The accuracy and reliability of point detectors could be improved by placing detectors at several points on the road surface, but this increase in the number of detectors would increase system cost.

One approach to an area detector would be the use of a radiometer which could scan preprogrammed areas. Such a device would be mounted above the road surface to measure spectral temperature, which is the product of actual temperature and surface emissivity. For example (for infrared light of 16 mm wavelength), the emissivity of dry pavement is about 0.8, ice about 0.4, and water about 1. No such device is commercially available now, but the FHWA plans to explore its feasibility.

Another approach considered by the FHWA uses motorists to detect ice. Since drivers slow down when they perceive a hazardous condition, it may be possible to detect preferential icing on a long bridge by noting the deceleration of vehicles on the bridge. By coupling this information with a measurement of pavement temperature and, perhaps, some other environmental parameter, only a small number of vehicles would be needed to predict the presence of ice. Perhaps such a system would be of greater use than a conventional ice detector because it could detect other hazardous situations as well.

Summary

Ice detectors for activating a sign must detect all icing events with high reliability and a low false alarm rate. At present, it is difficult to meet both of these requirements. The weather conditions that cause ice and snow to accumulate on pavement can be marginal, with residual deicing chemicals and the effects of traffic complicating the matter.

Ice detectors do not always "see" the same icing condition the motorist does. For one thing, in-pavement detector heads are often recessed to prevent damage by snowplows. Water or ice may accumulate in the depression.

The detector heads are made of a material different from that of the road and therefore can possess different thermal properties. Some detectors use methods which may actually alter the conditions they are supposed to detect.

Finally, the highway environment is harsh. Water, deicing chemicals, snowplow blades, chains, and heavy trucks all abuse the in-pavement detector heads. The controller units located beside or beneath the bridge deck are particularly subject to moisture and severe temperatures.

To date, no ice detector demonstrated has solved all of the above problems. Recent improvements may hold some promise, but a radical departure from the point detector may be the most feasible way for activating an ice warning sign.

REFERENCES

(1) W. D. Glauz, R. R. Blackburn, et al., "An Ice Detection and Warning System Feasibility Study," Final Report, Contract No. FH-11-74-28, *Federal Highway Administration,* Washington, D.C., 1971.

(2) R. C. Mawhinney, C. C. Lovell, and R. J. Ruden, "Snow and Ice Detection and Warning Systems," Final Report No. FHWA-RD-76-25, *Federal Highway Administration,* Washington, D.C., 1975.

(3) F. R. Hanscom, "Driver Awareness of Highway Sites with High Skid Accident Potential," Final Report No. FHWA-RD-74-66, *Federal Highway Administration,* Washington, D.C., 1974.

(4) H. L. Crane, "Study of Frost and Ice Prediction System on the Rouge River Bridge," Final Report, *Michigan Department of State Highways and Transportation,* 1974.

(5) N. K. Fox, "Development of a Frost and Ice Detection System for Highway Bridges," Transportation Research Report 576, *Iowa State Highway Commission,* 1976.

(6) T. J. Nelson, "Ice Detection Sensors and Information Signing," Final Report, *Oklahoma Department of Highways,* 1975.

The Traffic Evaluator System: An Innovative Data Collection Tool

by James H. Sanders, Wallace G. Berger, and Fred R. Hanscom

Traffic Evaluator System in the field.

The first generation Traffic Evaluator System (TES) was developed and constructed by the Federal Highway Administration (FHWA) in 1969. Since then BioTechnology, Inc., has been the prime user of the system, developing performance modifications to the hardware and software packages. The FHWA's Office of Development, Engineering Services Division, has developed a second generation of the TES. A discussion of the hardware improvements of the second generation TES will be reported in a future article in *Public Roads*.

The Traffic Evaluator System is an electronic system which collects computer readable data on traffic flow. The system permits computer reconstruction of the interactions among all vehicles as they pass through an instrumented segment of highway as well as completely describes each vehicle and its trajectory. This powerful research tool has been used by BioTechnology, Inc., since 1969. This article describes the system and some of its applications.

Introduction

In collecting traffic flow data many techniques have been used, each representing a compromise between resolution and cost. The more detail which is recorded, the more expensive, complicated, and time consuming the technique becomes.

The complete behavior of traffic over a limited segment of roadway could be recorded by aerial time lapse photography. Exposures made, say, 1 second apart could be examined in sequence and individual movements could be followed. Film is not a machine readable medium, however, and the cost of converting the behavior of thousands of vehicles for computer analysis is prohibitive.

This article describes an electronic system which collects most of the same information that can be recorded on film; however, it collects data with electronic precision using tire sensors taped to the road surface. Computer programs, which have been in use for several years, are used to track every vehicle through the instrumented section of road. The interactions among vehicles and the behavior of individual vehicles may be examined in fine detail at low cost since the system collects the data on magnetic tape and no manual effort is necessary to transform the data into useful information.

Figure 1.—TES electronics chassis is readily removable for testing and troubleshooting.

The Traffic Evaluator

The Traffic Evaluator System (TES) was developed in 1969 by the Federal Highway Administration (FHWA) and BioTechnology, Inc., to facilitate the large-scale collection of traffic flow data. Major components of the TES include:

- An array of tapeswitches that transmit an electrical pulse when vehicle presence is detected (input).
- An electronic coding unit, a digital tape recorder, and an electronic clock.
- A series of computer programs that reconstruct the actions of the vehicles and prepare descriptive and inferential statistics.

The TES (fig. 1) is a rugged, portable, battery-operated research tool that continuously monitors 60 switch contacts. While most of the contacts usually are used for the tire detector switches, the remainder can be used for manual event coding.

The operation of the TES is shown in figure 2. Upon activation of any switch contact, the time of initial closure and the identification number of the active switch are recorded on a seven-track

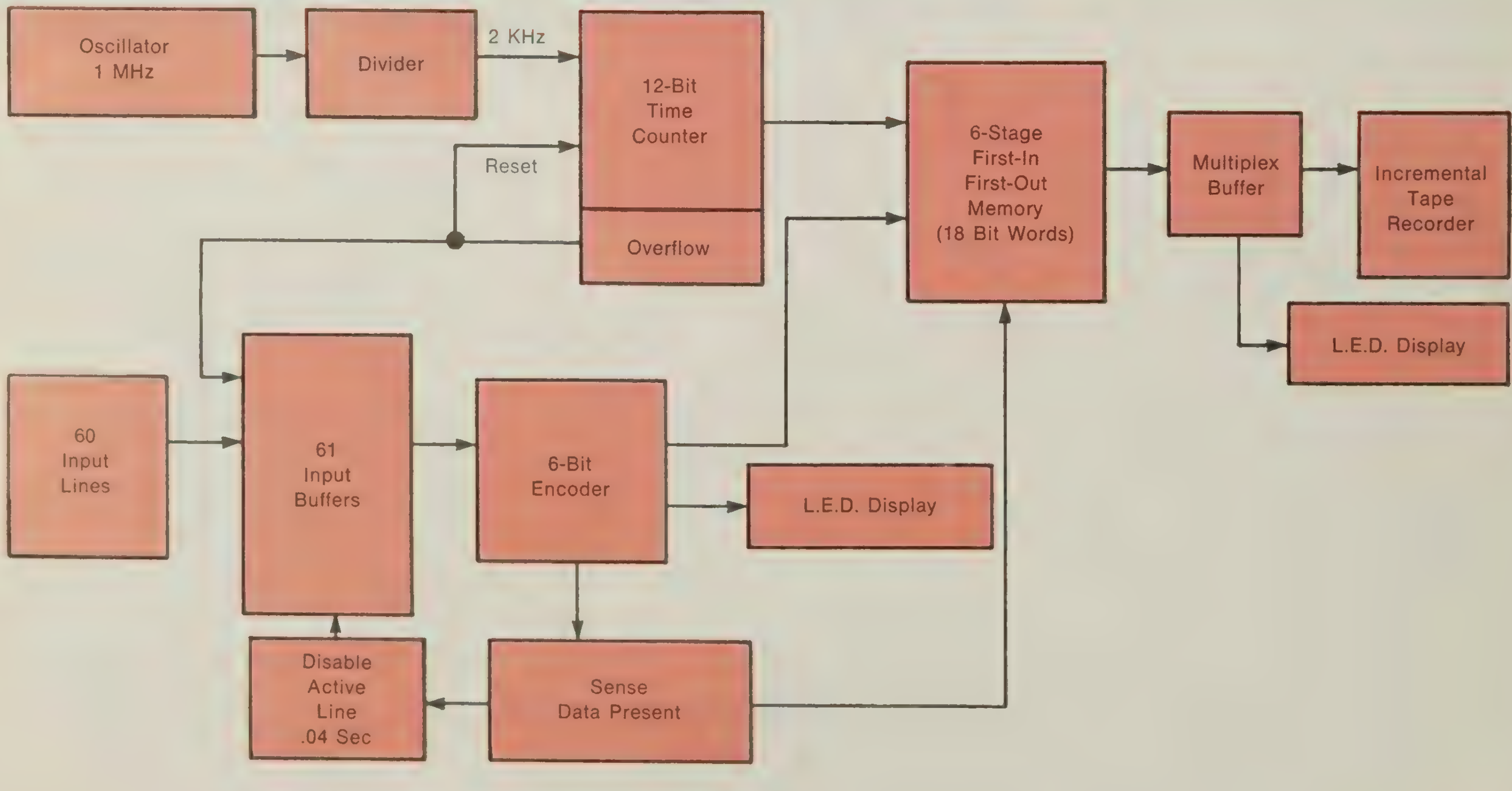


Figure 2.—TES operation.

computer tape. The processing of these data tapes can yield the following measures for each vehicle passing through the array: lane changes, velocity, relative speed, headway, gap, acceleration, number of axles, and wheelbase.

Wheelbase and number of axles are, of course, constant for a given vehicle traversing the tapeswitch array. However, each of the other measures is generated at a number of points along the highway, depending on the position of tapeswitches and their distance from a selected point of interest such as an interchange gore area. The data can also be aggregated to yield summary statistics such as the number of vehicles in each lane, mean speed, and mean headway.

Tire Sensors

The tapeswitch sensors consist of two metal strips separated by plastic spacers and enclosed in a protruding plastic jacket. The switches are available in any length. When the vehicle's tire rolls onto the switch at any point along its length, the metal strips are pressed together to complete an electrical circuit. The switches are placed on the road by affixing double-faced tape to the underside of the switch, attaching it to the roadway, and covering the switch with a layer of wide, dark-green duct tape. The switches are placed in pairs normally 4 ft (1.2 m) apart to provide the required speed measures. Figure 3 shows a typical switch deployment.

Because of the switches' low profile (3/16-in [5 mm] thick) and the color of the duct tape, drivers seldom notice them. If tape is used to affix the tapeswitches, the roadway must be dry during placement. Switches adhered by tape perform well for 3 or 4 days on interstate highways with daily volumes in excess of 100,000 vehicles. On low volume secondary roads, a lifetime of several weeks may be expected. Rapid deceleration over the switch, as in panic stops, is the major cause of switch attrition.

Event Coding

When the entire TES input capacity is not required for wheel switch closures, some of the 60 available codes may be used to record other discrete events. The most common procedure for coding events uses momentary pushbutton switches provided with the system. The meaning of these "special" codes may be defined in any way desired. For example, out-of-State license plates, driver head movements, pedestrian location, and the approach of a train have been manually coded using the code boxes. Other nonmanual procedures may also be used to provide inputs to the TES. Direct connections to a traffic control box have, for example, been used to record signal status and loop detector activations.

The TES recognizes these inputs and associates a time with their occurrence. The computer programs can then match these codes with the appropriate vehicle (for example, by license plate) or vehicles (for example, by train in sight). This "hookup" between these event codes and a specific vehicle has been used to correlate a driver's action with his or her response to a survey conducted downstream.

The TES Hardware

The Traffic Evaluator System is designed to operate on a portable battery box containing a 12-volt automobile storage battery for the digital tape recorder, a 6-volt storage battery for the electronics unit, and a 12-volt dry cell for the road sensors. The recorder draws 40 watts when writing data and virtually no power in the standby mode. A current usage of approximately 2 ampere-hours (7,200 coulombs) is considered average, depending on the characteristics of the vehicle array and traffic volume. The electronics package draws a steady 25 watts from the 6-volt battery, while the drain on the switch supply is negligible.

The system is connected using a series of 60 interchangeable cables, each 328 ft (100 m) long, that can be hooked together in the manner of household extension cords to obtain the necessary length. Amphenol connectors terminate the cables at the Evaluator on one end

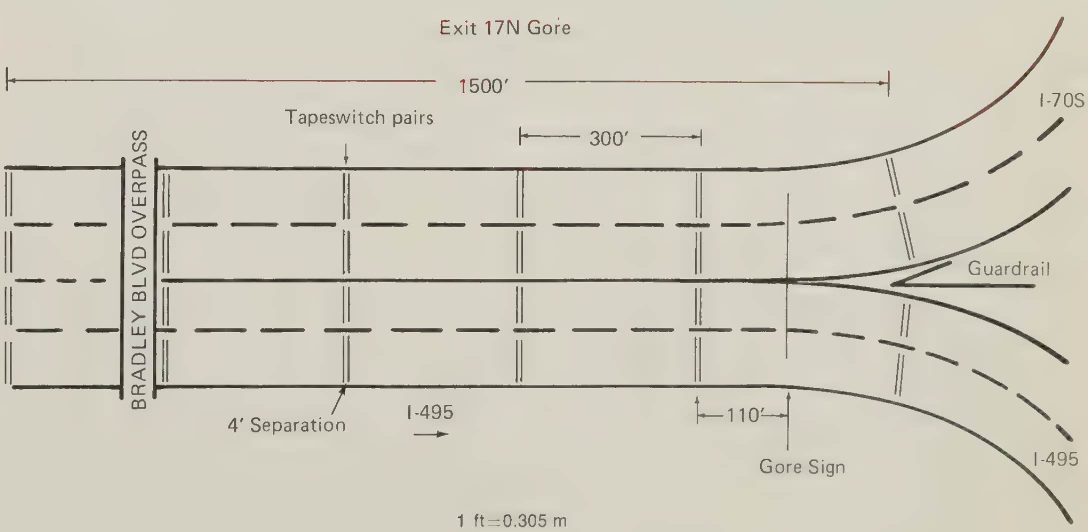


Figure 3.—Tapeswitches on I–495 near gore of interchange 17 northbound in Maryland.

and at either the manual code box or road switch terminal strip box on the other.

The Evaluator consists of an electronics unit that codes incoming data and a digital tape recorder for mass storage.

The mass storage device is an incremental digital tape recorder. Completely passive unless commanded to record, this instrument writes six bits of data plus parity at each step. It takes 15 milliseconds for three steps required to write the 18 bits of data generated by each switch closure. Maximum writing speed is 200 steps per second. Six-hundred-foot (183 m) tapes are used, representing a maximum of 480,000 switch closures per reel.

A typical data collection period involves the recording of up to 50,000 vehicles.

The Evaluator in the present configuration contains a memory which can retain the data (time and switch code) for up to six switch closures. The tape recorder is able to write up to 66 switch closures per second; when data arrive more frequently, the memory is used to carry the peak bursts.

Error Sources

Physical sources of error bear noting. The vehicle might not cross a switch pair perpendicular to the switches, thereby generating a timing error equal to the cosecant of the angle. Other factors such as poor axle alinement or unevenly worn tires on a vehicle can cause a timing error. Switch pair separations greater than 4 ft (1.2 m) could be used to reduce the percentage of error due to some sources, but the pair becomes more sensitive to error caused by acceleration of a vehicle. The most practical means for achieving error reduction is to average the speed of all axles. All of the sources of error are small relative to the more conventional data collection techniques, such as radar, manual coding, and time-lapse.

TES Software

Two utility computer programs and one analytical program are used to prepare data obtained in the field with the Traffic Evaluator System. These programs translate time and switch codes into vehicle and traffic flow characteristics, reproducing the conditions actually experienced on the roadway.

The utility programs edit data stored on magnetic tape in the field and arrange these data into a form more readily reviewed by a research engineer. Data in each record is translated from continuous binary bits into three-word elements of six bits per word. The first two words, or 12 bits, represent the time; the third word represents the switch code.

The edit program also provides the user with a means for selecting specific blocks of field data to be processed by the analytical program. Input controls are provided to specify the beginning and ending file and record numbers of field data to be stored for further analysis. In addition, the user is given the options of having the processed data printed in octal or decimal and writing the data on magnetic tape.

It is the primary function of the analysis program to reproduce the field situation that was originally stored on magnetic tape. Axle time impulses and the associated switch codes are used to reproduce vehicles at each pair of switches in each of up to four lanes of roadway. The program assigns a unique identification number to each vehicle entering the array and tracks this vehicle through the entire array of switches on the roadway. As vehicles are determined by the program, the interrelationship of each with adjacent vehicles in the lane is computed in terms of time and space headway. These vehicle relationships and other space and time measures are output both on magnetic tape and in printed tables.

A number of user-generated input items are provided to permit maximum user control of the data to be processed. Among these are parameters that define analysis periods, locate and identify valid switch codes by lane, and establish ranges and intervals for tabulation of the data. Time and space factors are included for fitting the analysis program to the traffic conditions that prevailed when the data were recorded.

Software Products

The output of the analysis program is stored on magnetic tape and provides the researcher with the greatest flexibility for conducting many different statistical tests on the traffic measures. By sorting the data on the file with a standard computer utility sort program, any of the fields in the record can be selected as the major control field and any other data in the record as minor control fields, creating any desired set of data for final analysis. For each vehicle at each switch pair crossed, the following 15 elements are recorded: vehicle number, lane number, switch pair number, vehicle type, wheelbase, number of axles, mean speed of all axles, time of day, manual codes associated with this vehicle, time gap to lead vehicle, space gap to lead vehicle, type of lead vehicle, time gap to following vehicle, space gap to following vehicle, and speed of following vehicle.

Computer analysis of the reconstructed vehicle records may be readily undertaken to answer specific requirements. An example is the determination of gap acceptance for lane changing vehicles.

An important feature of the analysis program is its capability to determine when failures of road switches have occurred. Original data that is missing from the input file of times and switch numbers can frequently be reconstructed and used by the program without causing the vehicle to be lost from the output data file. Many internal checks are performed before permitting the reconstruction of missing data, enabling the output to be used with great confidence.

Applications

The TES is applicable in nearly any traffic situation where flow characteristics are to be studied. However, there are certain limitations on operational setting. First, a hard pavement surface is required for adhesion of the tapeswitches. No operational experience exists demonstrating use of the TES on a dirt or gravel surface. Use on extremely porous pavement during rainy weather is not recommended for data collection, as the capillary action of water in the pavement will wet the surface beneath the tapeswitches and destroy their adhesion.

Second, traffic should be relatively free-flowing because stop-and-start traffic, characteristic of an urban intersection, violates certain basic assumptions of TES software. Also, the TES cannot accurately determine conditions when a vehicle wheel is stopped on a tapeswitch.

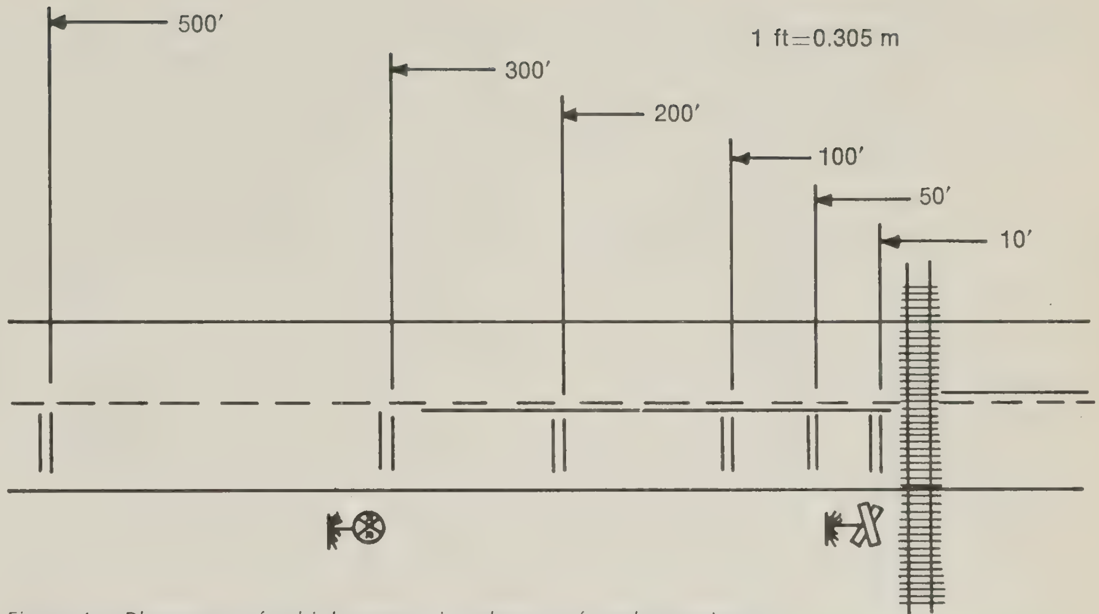


Figure 4.—Placement of vehicle sensors in advance of grade crossings.

Finally, the instrumented segment of the roadway should not include any intersecting roads. Intersecting roads will result in the "phantom vehicle" phenomenon in which vehicles "appear" and "disappear" in the middle of the array, although software has been designed to handle special situations where intersecting roadways are present.

Railroad-highway grade crossings

The TES has been used in two railroad-highway grade crossing studies to determine driver approach speed profiles. During one study, vehicles were tracked for 3,000 ft (915 m) at each of 26 grade crossings, with several detectors placed on both sides of the crossing and at the crossing. (*1*)[1] To generate smoother speed profile curves during the second study, switches were spaced as shown in figure 4. (*2*) This array provided measures of vehicle parameters at six points within 500 ft (152 m) of the crossing at approximately regular time intervals during vehicle deceleration. The speed measures obtained represent the speed of the motorist under study conditions both before and while under the influence of the grade crossing.

Manual coding inputs to the TES were used to record visible driver behaviors. For each vehicle passing during the period of observation, the "looking" behavior of the driver was coded by hidden observers. The approach to the crossing was divided into two zones and the obvious head movements of the driver were coded by four categories: (1) did not look, (2) looked to the left, (3) looked to the right, and (4) looked both ways.

Additional codes were used to describe environmental effects at the crossing. TES input was used to represent the start and end of crossing signal activation, the arrival and departure of trains, and the sound of a train whistle. A code was used for the designation of motorists selected to receive interviews. Motorists were selected for interviewing on the basis of observed target behaviors, which included stopping at the crossing when no train was in sight and proceeding across when the signal

[1]Italic numbers in parentheses identify the references on page 155.

was activated. Questionnaire responses and vehicle performance were matched and then analyzed.

Interstate highway interchanges

Two study efforts have used the TES to gather vehicle data relative to motorists' responses to guide signs. Data was gathered both at the gore area and in advance of the interchange. One study (*3*) was an evaluative effort to determine the effect of a new guide signing concept and dealt with aggregated responses from many motorists. The other study (*4*) was concerned with the determination of guide sign related measures and involved highly detailed vehicle performance data matched with questionnaire responses of specific motorists.

The first study concerned the following measures for the total vehicle population at an interchange: lane placement (the proportion of vehicles in each lane as the ramp is approached), speed differences (the proportion of vehicles traveling 5 mph [8 km/h] or more slower than the mean speed), and headway violations (the proportion of vehicles exhibiting a headway of 1 second or less). In the analysis, it was essential to present these data for thousands of vehicles in each of four lanes in an easily interpretable form.

The second study was dependent upon highly detailed vehicle performance data which could be extensively analyzed in light of questionnaire responses for a relatively small sample of drivers. Thus, the TES was used to gather a larger variety of data that was amenable to extensive treatment and format modification during analysis. A sample printout of measures obtained is shown in figure 5.

Curves on secondary roads

An FHWA study (*5*) used the TES to examine motorists' awareness of skidding hazards on curves. Tapeswitch pairs were located in advance of the curve, at the curve entry point, at the point of sharpest curvature, and at the curve exit point. Headways gathered by the TES were used to isolate free-flowing vehicles for analysis.

TES driver response measures were vehicle speeds at critical curve locations, speed profiles throughout the array, and overall acceleration and deceleration behavior, all of which were compared for wet versus dry pavement conditions. Driver questionnaires were matched to individual vehicle data to further determine driver responses both to the general hazard and experimental warning signs.

A similar application of the TES and study technique was made to examine driver awareness of potentially icy bridges. A special configuration of switches was used in this study to

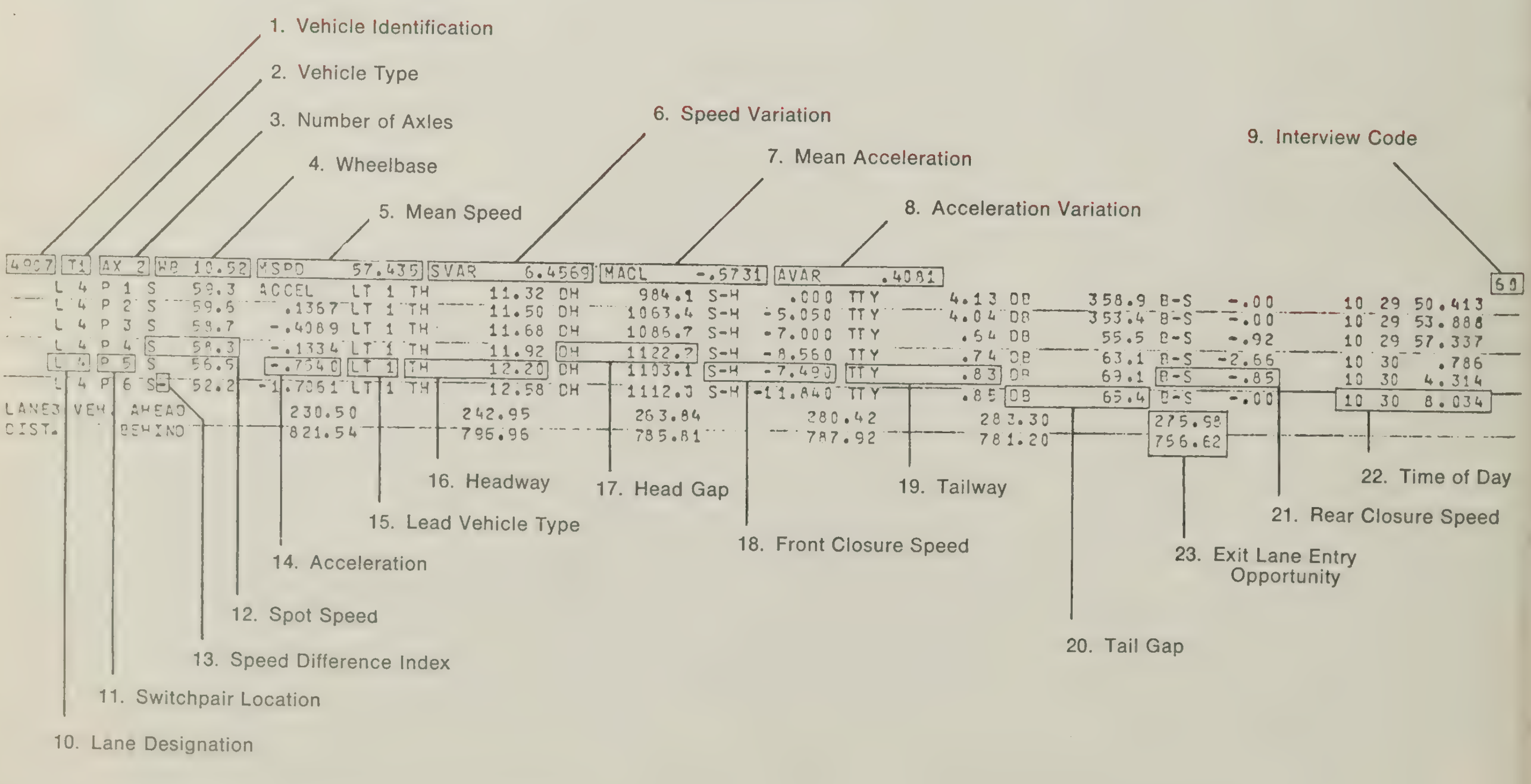


Figure 5.—Example of computer printout of TES measures.

measure lateral lane position. A switch was placed at a 60° angle to the traffic immediately after a standard pair. The time and speed relationships were then used to calculate the distance of the outside wheel to a reference line.

Other applications

The versatility of the TES has resulted in a myriad of potential applications. By varying the placement of switches on the roadway and writing new analysis software, the TES can be modified to study traffic flow in almost any situation. One suggested application is its use in characterizing hazardous flow behavior and evaluating remedial countermeasures in a mainline lane drop situation.

The TES software permits the selection of any well-defined subset of the vehicles for analysis. For example, the engineer might be concerned with the lane changing behavior, gap acceptance, or closure rates of those vehicles in the dropped lane. These data not only can be used for assessing the countermeasure's effectiveness, but also for providing insight into the reason for its effectiveness.

A sound evaluative procedure would be to obtain a profile of several traffic characteristics in relation to the distance from the end of the drop lane taper. The following traffic characteristics can be derived from the TES for several predetermined points near the lane drop:

- Percentage of lane changes for each lane.
- Headway envelopes for each lane.
- Speed envelopes for each lane.
- Average gap acceptance in lane changing.
- Vehicle closure (relative speeds) envelopes for each lane.
- Average acceleration noise for each lane.

An advantage of the TES over conventional data collection techniques is that each of the traffic characteristics cited above can be precisely obtained under both day and night conditions. This feature is necessary for a thorough evaluation of the effectiveness of reflectorized delineation.

Before and after data can be rigorously compared through the direct application of statistical treatments in the analysis software. A variety of techniques, from basic descriptive treatments through classical techniques such as analysis of variance, pair comparison tests, and chi-square tests, can be included in a "post-analysis" TES software package.

REFERENCES

(1) J. H. Sanders, "Speed Profiles and Time Delay at Rail-Highway Grade Crossings," Report No. FHWA-RD-72-22, *Federal Highway Administration,* Washington, D.C., May 1972.

(2) J. H. Sanders, G. S. Kolsrud, and W. G. Berger, "Human Factors Countermeasures to Improve Highway-Railway Intersection Safety," Report No. DOT-HS-800-888, *Federal Railroad Administration and National Highway Traffic Safety Administration,* Washington, D.C., June 1973.

(3) G. S. Kolsrud, "Diagrammatic Guide Signs for Use on Controlled Access Highways. Vol. III—Traffic Engineering Evaluation of Diagrammatic Guide Signs; Part 2—The I-495 (Capital Beltway)/I-70S Field Study," Report No. FHWA-RD-73-24, *Federal Highway Administration,* Washington, D.C., December 1972.

(4) F. R. Hanscom and W. G. Berger, "Motorists' Response to Highway Guide Signs," Interim Report No. NCHRP 3-21, *Transportation Research Board,* Washington, D.C., July 1975.

(5) F. R. Hanscom, "Driver Awareness of Highway Sites with High Skid Accident Potential," Report No. FHWA-RD-74-66, *Federal Highway Administration,* Washington, D.C., July 1974.

Federal Highway Administration Regional Offices:

No. 1. 729 Federal Bldg., Clinton Ave. and North Pearl St., Albany, N.Y. 12207.
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Puerto Rico, Rhode Island, Vermont, Virgin Islands.

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

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

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

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

No. 7. P.O. Box 19715, Kansas City, Mo. 64141.
Iowa, Kansas, Missouri, Nebraska.

No. 8. P.O. Box 25246, Bldg. 40, Denver Federal Center, Denver, Colo. 80225.
Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming.

No. 9. 2 Embarcadero Center, Suite 530, San Francisco, Calif. 94111.
Arizona, California, Hawaii, Nevada, Guam, American Samoa.

No. 10. Room 412, Mohawk Bldg., 222 SW. Morrison St., Portland, Oreg. 97204.
Alaska, Idaho, Oregon, Washington.

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

No. 19. Drawer J, Balboa Heights, Canal Zone.
Canal Zone, Colombia, Costa Rica, Panama.


Project R-23 will evaluate the impact of maintenance budget cutbacks on roadside maintenanc

Development of a National Highway Maintenance Research and Development Program

by William C. Besselievre

Introduction

The United States has the most envied transportation system in the world. The backbone of this system is its highways, a network of almost 3.8 million miles (6.1 million km) of roadways which accommodate 90 percent of the passenger miles and 25 percent of the commodity ton-miles in the United States. Yet, in 1973, when nearly $6 billion was being spent to maintain this enviable highway network, only a very small percentage of highway construction and maintenance funds was used to finance maintenance research and development. The research and development efforts that were financed were virtually uncoordinated.

This state of affairs was unsound. If highway maintenance forces were to cope with the increasing demands being made upon their limited resources, they would need the advanced technological tools and ideas that a large, coordinated research and development effort could provide.

The Federal Highway Administration (FHWA) recognized this need. On March 28, 1974, its Office of Development, Implementation Division, contracted the National Research Council's Transportation Research Board (TRB) to formulate a national highway maintenance research and development program. After a 1-year effort, the TRB identified the research and development projects that highway maintenance forces felt were the most needed and determined the relative priority of each of these projects.

Identifying the Most Needed R&D Projects

To identify the most needed research and development projects, the TRB brought together representatives of the major segments of the highway maintenance community: representatives of highway agencies, educational institutions, consulting firms, and industries. Since these individuals were from all regions in the United States, their collective views reflected national, rather than regional, needs. After a series of consultations, they identified the most needed R&D projects. Only those projects which promised to benefit the highway maintenance community within 5 years were included in the final highway maintenance research and development program.

The development of the program began in April 1974 when the TRB created a steering committee, which was called the Advisory Committee for a Study on Maintenance Research and Development Needs (task force A3T52). Comprised of 13 (later 15) members, each a nationally recognized leader in the field of maintenance, the committee was responsible for overseeing the formation of the research and development program.

Once created, the committee acted quickly. In May, it organized and directed a meeting which was held in Homewood, Ill. About 75 percent of the approximately 50 attendees were maintenance engineers from States in FHWA's Region 5 (Minnesota, Wisconsin, Illinois, Indiana, Ohio, and Michigan). During the meeting the first list of needed R&D projects was made. At the end of the meeting, a vote established a rough priority of the projects identified.

In September, the steering committee organized two more meetings—one in Atlanta, Ga., the other in Arlington, Tex. These two meetings attracted about 100 maintenance authorities from States, counties, and universities throughout the Southeast, Southwest, West, and Northwest. These meetings differed from the first meeting. In Atlanta, the conference began with a proposed program, one which had been formulated from the needs list developed at Homewood. After a series of discussions, 14 major problem areas were identified. In Arlington, these problem areas were refined to the nine major problem areas that would form the basis of a national workshop meeting to be held in October at Lost Valley Ranch, Colo. (table 1).

Sixty maintenance experts from all parts of the United States attended the Colorado meeting. At this meeting, the participants were divided into nine separate discussion groups (workshops). Each workshop corresponded to one of the nine major maintenance problem areas identified at the Arlington meeting (table 1). A group leader led the workshop discussions and assumed the overall responsibility for meeting the workshop objectives.

The workshops were conducted over a 3-day period. Each opened with state-of-the-art reports which had been prepared in advance. After this introduction, each group met for two separate half day sessions to formulate the projects that were to be included in each major problem area. For each research and development project, the workshop participants were required to do the following:

- Prepare a problem statement and describe the research and development effort that would be required (usually a 400–600 word narrative would suffice).
- Recommend the type of organization that could best perform the work (for example, State highway department, consulting firm, university, or industry).
- Estimate expenditures required.
- Determine the priority of the project relative to other research and development projects in its problem area.
- Estimate the time required for the effort.

By the time the Colorado meeting ended, the workshop participants had identified 28 projects, each of which was

Table 1.—Identification of recommended maintenance research and development projects

Program area	Project number	Project title
Group 1—Winter Maintenance	R1	Pavement Surface Quality Assessment for Winter Maintenance
	R2	Development of Standard Snowplows
	R3[1]	Nonchemical Highway Ice Disbonding Systems
	R4[1]	Winter Maintenance Chemical Management
Group 2—Maintenance Work Site Evaluation	R5[1]	Traffic Control Through Maintenance Work Sites
Group 3—Maintenance Management	R6	Optimizing Expenditure of Maintenance Resources
	R7[1]	Synthesis of Equipment Management Systems
Group 4—Quality of Service	R8	Maintenance Quality-of-Service Guidelines for Pavement Systems
	R9	Development of a Methodology for Establishing Quality-of-Service Guidelines
	R10	Guidelines for Building a State Highway and Transportation Data Storage and Retrieval System
Group 5—New Concepts	R11[1]	Effect of Increased Vehicle Weights and Dimensions on Maintenance
	R12	Integration of Maintenance Needs Into Preconstruction Procedures
	R13	Evaluation of Intergovernmental Responsibilities for Maintenance
Group A—Structure Maintenance	R14[1]	Structural Evaluation of Existing Bridges for Load-Carrying Capacity
	R15	Environmentally Safe Steel Bridge Cleaning Method
	R16	Reduce Number of Expansion Joints in Existing Bridges
Group B—Pavement Repairs	R17	Rapid Replacement of Portland Cement Concrete Pavement
	R18	Rapid Removal of Portland Cement Concrete Pavement
	R19[1]	Prediction of Pavement Blowups
	R20[1]	Pavement Management System for Fiscal Evaluation of Maintenance Strategies
	R21	Quantification of Pavement Maintenance Requirements
	R22[1]	Improved Pavement-Shoulder Joint Maintenance
Group C—Roadside Maintenance	R23	Impact of Deferment of Roadside Maintenance
	R24	Litter Pickup Systems
Group D—Equipment Development	R25	Equipment for Economical Recycling of Highway Materials for Maintenance
	R26	Development of Hydraulic Tools for Maintenance Activities
	R27	Standardization of Motorized Maintenance Equipment
	R28	Mechanization of Patching

[1]Projects eventually eliminated from program.

categorized in one of the nine major maintenance problem areas. These 28 projects with the alphanumeric codes they were assigned are listed in table 1.

Priorities Established

Although the workshop committees had estimated the relative priorities of each of the projects, more information was needed before determining the final priority ranking of each project. The TRB used the Delphi Technique to obtain this information. Questionnaires were sent to individuals familiar with highway maintenance disciplines. Each person receiving a questionnaire was asked to evaluate his ability to judge each proposed project (using a numbering system from 1 to 5) and to estimate the costs, the benefits, and the duration of each project. Individuals who had indicated an expertise level of 3 or higher on the questionnaire were sent a second questionnaire along with a summary of results of the first questionnaire. The purpose of the Delphi Technique was to achieve a basic consensus among participating individuals by sending them a series of questionnaires and summaries of

Table 2.—Recommended national maintenance research program

Level of funding	Project by priority	Project description	Research cost	Expected benefits	Priority group	Risk level	Project time
			Thousands of dollars	*Millions of dollars*			*Years*
	R6	Optimizing expenditures	382.5	125.00	High	Low	5
	R25	Recycling materials	577.4	79.95	High	High	5
	R12	Integrate maintenance into preconstruction	415.8	53.20	High	Medium	4
$1.8 million	R8	Quality of service	433.5	53.28	High	Medium	4
	R23	Impact of deferred maintenance	554.4	58.88	High	Medium	4
	R1	Icy surface quality measuring device	520.0	51.06	High	High	5
	R28	Mechanization of patching	581.8	47.45	Medium	High	5
$4.0 million	R27	Standardized equipment	526.7	41.62	Medium	High	4
	R24	Litter pickup	405.4	30.40	Medium	Low	4
	R9	Methods for estimating quality guide	366.9	27.07	Medium	Low	3
	R2	Snowplow design	347.2	24.95	Medium	Low	3
	R13	Intergovernmental relations	221.7	14.01	Medium	Low	3
$5.9 million	R17	Portland cement concrete pavement replacement	547.9	29.12	Low	Medium	4
	R16	Reduced number of bridge expansion joints	355.2	17.09	Low	Low	5
	R18	Rapid pavement removal	534.3	24.33	Low	Medium	3
	R21	Quantify pavement requirements	820.0	29.95	Low	High	5
	R15	Bridge steel cleaning	375.4	13.70	Low	Low	3
	R26	Hydraulic tools	435.6	15.86	Low	Medium	3
$9.0 million	R10	State data file	683.6	22.09	Low	High	4
			9,085.3	759.01			

Project R–28 will reduce the labor requirements and increase the safety of patching operations while upgrading the quality of patches.

Project R–2 will develop high-quality standard specifications for all truck-mounted snowplows. The specifications for each plow will permit the plow to be used on any vehicle in a particular weight class.

the results of previous questionnaires until their opinions converged.

Lack of time, however, forced the TRB to limit the questionnaire series to two rounds. Nonetheless, the 132 eligible responses received at the end of the second round (out of 497 questionnaires initially mailed) provided enough statistical information to form a valid program. The frequency distribution pattern of costs, benefits, and time information was interpreted. Benefit/cost ratios were determined. The project risk—the chance of completing the project with the estimated funds—was estimated by analyzing the variability of the responses received.

Once those projects that were already included in the FHWA's Federally Coordinated Program of Research and Development in Highway Transportation (FCP) were eliminated along with project R7, which was more a state-of-the-art project than a research project (table 1), the National Maintenance Research and Development Program was drafted. The program is summarized in table 2. In March 1975, a report was published [1] describing the program and the studies leading to it. In September 1975, the program became the basis of a new study category in the FHWA's FCP: Category 7—Improved Technology for Highway Maintenance. For a cost of $50,900, a program had been formulated which had the potential of yielding $759 million in benefits if a $9.1 million long term research and development effort was made.

[1] "Highway Maintenance Research Needs," Report No. FHWA–RD–75–511, *Federal Highway Administration,* Washington, D.C., March 1975. Available from the Implementation Division (HDV–22), Office of Development, Federal Highway Administration, Washington, D.C. 20590.

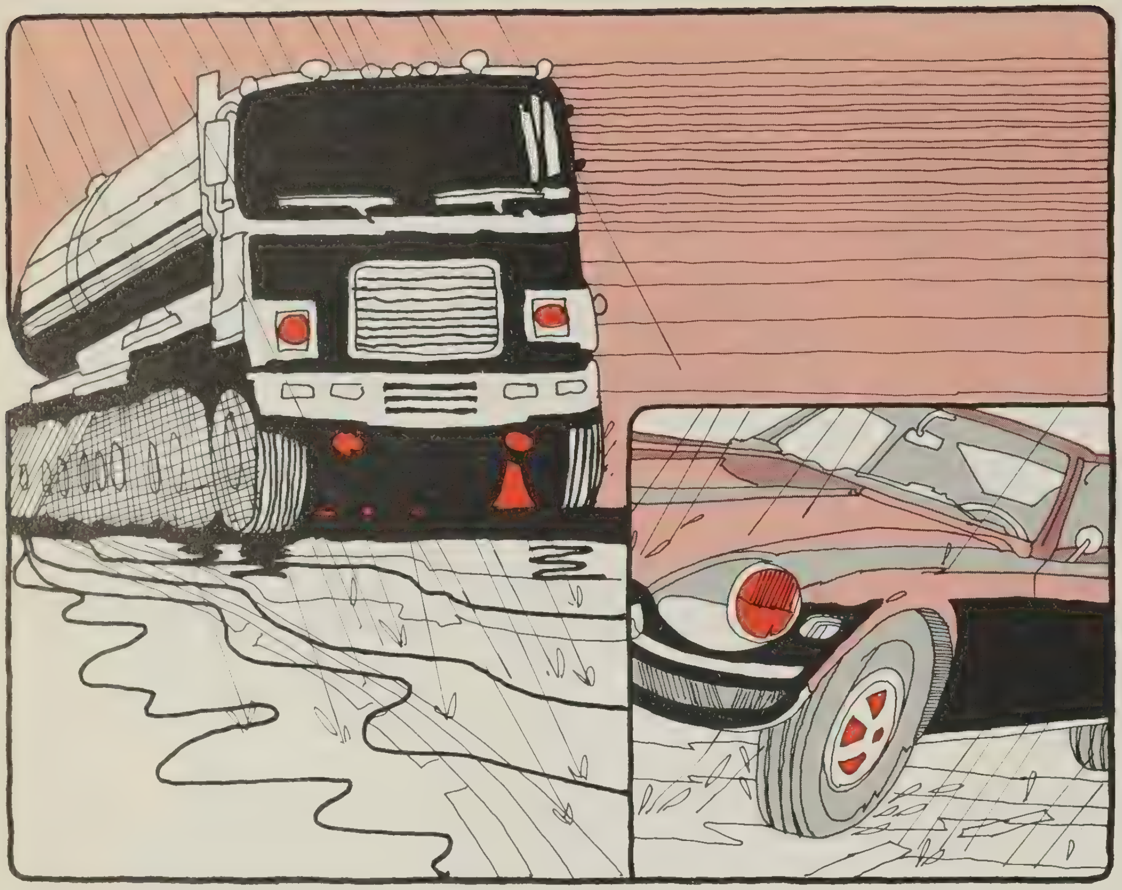
Errata

In the article "Concrete Roads in Belgium" in the December 1976 issue of *Public Roads*, vol. 40, No. 3, the Belgian specifications for compressive strength of concrete (English and metric values) were incorrect on page 123, columns 2 and 3. The correct values appear below in bold face type:

The Belgian Ministry of Public Works, as provided by the specifications for freeways and state highways (*1*),[2] wants to be statistically sure that for 95 percent of the pavement the compressive strength shall exceed the minimum threshold value of **8,534 psi (58,840 kPa).** Thus the minimum value to be obtained for the average of all the results depends on the standard deviation. For example, for a standard deviation of **1,024 psi (7,060 kPa)**—a frequently observed standard deviation—the average compression strength ought to be as high as **10,240 psi (70,610 kPa).** Failure by a contractor to comply with this requirement will result in a monetary penalty and may even result in the work not being accepted. Most contractors find it is easy to satisfy the requirements due to the high cement content, the high compactness—dry volumetric weight of 144 pcf (2,300 kg/m^3) —and the comparatively low water content.

The compressive strength requirements for provincial and local roads are, of course, less severe, averaging at 56 days **8,534 psi (58,840 kPa)**, and even less, say **5,690 psi (39,230 kPa)**, for rural roads. (*2*) Thus for these rural roads, the concrete contains less cement, **6.2 bags/cubic yard (300 kg/m^3)**, and the sand content is higher.

Additional corrections are as follows: Page 127, col. 2, par. 1, change 580 psi (4,000 kPa) to 5,690 psi (39,230 kPa); page 129, col. 3, last paragraph, change 27,578 psi (4 MPa) to 56,854 psi (392 MPa); and page 130, col. 1, par. 1, change 28,958 and 34,473 psi (4.2 and 5 MPa) to 59,755 and 71,068 psi (412 and 490 MPa), and par. 5, change 34,474 psi (5 MPa) to 71,068 psi (490 MPa).



Seasonal Variations in Pavement Skid Resistance

by James M. Rice

It is well known that the skid resistance of wet roads is lower than that of dry roads. Accordingly, the frequency of accidents involving skidding is higher for wet pavement conditions than dry. Less well known is the fact that wet pavement frictional characteristics can vary significantly from season to season and also intermittently during a given season.

This article discusses these seasonal or temporal changes in pavement skid resistance by presenting background information, examples of changes which have been observed, and the possible mechanisms involved in the changes. Several consequences of variations in skid resistance are described and the Federal Highway Administration's approach to solving the problem is presented.

Introduction

An important factor in the safe operation of motor vehicles is the presence of friction or skid resistance at the interface of the tire and pavement surfaces, particularly during braking and/or cornering maneuvers. It is an established fact that when roads are wet, their skid resistance is substantially reduced due to the lubricating action of water films on both the tire and pavement surfaces. Unfortunately, most drivers seem unaware of the danger associated with this condition since they generally do not reduce their driving speeds under wet conditions except when their visibility is restricted. Thus, the frequency of accidents involving skidding under wet conditions is usually several times that for dry conditions.

In order to provide adequate pavement friction for high speed traffic under wet weather conditions, pavement surfaces should have the following characteristics: (1) microtexture or fine-scale grittiness, (2) macrotexture or large-scale asperities, and (3) a capacity for movement of water by crossflow or drainage below the surface of the tire-pavement contact area. Mineral aggregates comprise the bulk of the paving material exposed at the surface and are the primary determinants of microtexture and macrotexture. The drainage requirement can be met by the transverse grooving of portland cement concrete or the use of porous, open-graded asphalt mixtures—in both cases coupled with adequate crown or cross-slope. In addition, these properties should be retained under traffic and environmental exposure throughout the expected life of the surface.

It has been recognized for some time that pavement surface characteristics undergo seasonal changes which affect the frictional properties. The primary determinants are considered to be exposure to the polishing and wearing actions of traffic and exposure to weather, with the weathering effects—either chemical or physical—tending to offset the traffic effects. For asphalt surfaces, which make up the greater part of the U.S. highway system, minimum levels of skid resistance are generally observed in the late summer and early fall, with maximum levels occurring in the spring. Superimposed on these annual changes are short term variations attributable to the external factors such as amount and timing of rainfall, and possibly to contaminations from oily films, drippings, detritus, and other deposits on the surface. In addition to these real changes in pavement surface characteristics, temperature changes affect the properties of the tires involved in the skid resistance measuring system.

As a result of these factors, the measured skid resistance of a given surface can vary on the order of 10 to 20 or more skid numbers.[1] Thus, it is difficult to state with assurance what the skid resistance of a pavement is, other than at time of measurement, or what the minimum level of resistance will be. Nevertheless, there are requirements for the systematic identification of the levels of skid resistance on existing highway systems in order to evaluate surfacing materials and practices, and to take corrective measures. Since it would be difficult, if not impossible, to conduct all inventory surveys of skid resistance at the times when the skid numbers are minimum, and therefore most critical, there is a need for procedures to convert measurements to a common seasonal base. Ultimately, it would be desirable to develop factors involving traffic volume and type; temperature, climate, and season; and aggregate sources and surfacing types. These would then be applied regionally to make needed adjustments in measured skid numbers.

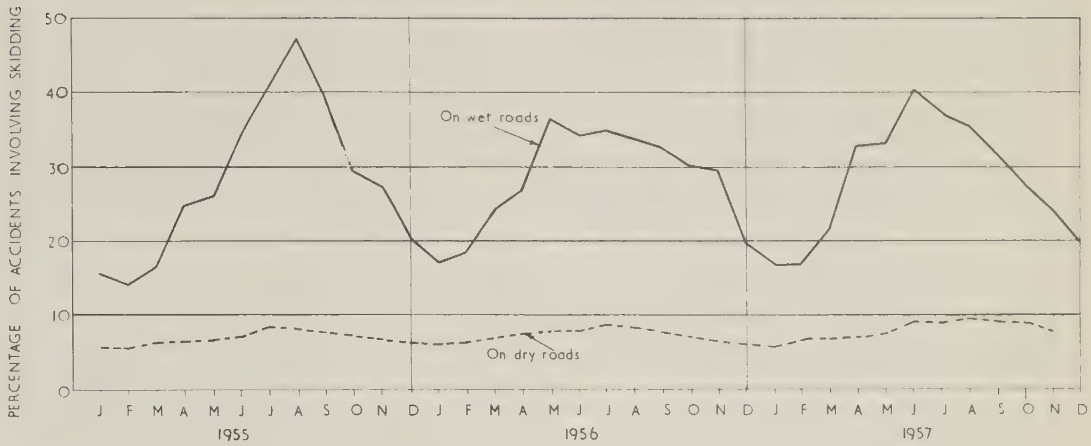


Figure 1.—Seasonal variation in skidding accidents: Data for personal-injury accidents in Great Britain, 1955–1957. (1)

Background

The phenomenon of seasonal variations in skid resistance has been known for many years. At the First International Skid Prevention Conference (1958), Giles and Sabey (*1*)[2] of the British Road Research Laboratory noted: "An important discovery that emerged from the skidding investigations carried out in Great Britain in 1931 was the fact that test results for wet surfaces showed a marked 'seasonal effect,' giving, for each surface tested, higher values in winter than in summer." One of the apparent consequences of higher skidding resistance in winter months was the lower incidence of skidding accidents as illustrated in figure 1. Giles and Sabey concluded that "Under British conditions, seasonal changes in coefficients are, on the average, of the order of 0.10 to 0.15, but on some roads differences between midsummer and midwinter as great as 0.3 have been measured." Two determining factors were identified: (1) the direct effect of temperature on changes in the hysteresis loss properties of rubber tires, and (2) changes in the fine-scale texture of the exposed aggregates brought about by polishing during long, dry periods (summer) and by roughening, probably as a result of weathering during long, wet periods (winter). At the same conference, Goetz and Rice (*2*) referred to these phenomena as "temporal effects" and noted that "tests spaced seasonally, daily, or rain to rain, may show significant differences." They noted that the effect of temperature was a factor, but that this and other factors needed further evaluation.

Seasonal Variations in the United States

While a number of State highway departments and other agencies have conducted fairly extensive research on pavement frictional characteristics under wet conditions, little research has been undertaken (until recently) to determine how these characteristics vary from season to season. There has also been little research on identifying quantitatively the causes of seasonal variations. In fact, some agencies are unaware of the phenomenon, and

[1]Skid number or SN is 100 times the coefficient of friction of a standard test tire on a locked wheel sliding on a wetted pavement, normally at 40 mph (64.4 km/h).

[2]Italic numbers in parentheses identify the references on page 166.

others, while recognizing that frictional properties undergo seasonal changes, doubt the urgency of the problem because they still question the direct correlation between accident frequency and measured skid resistance, and because in the past there has been a general lack of repeatability of measurements and lack of agreement among different skid test units. This article will show that some of this variation in measurement and many of the questions related to correlation between skid properties and accidents may be due to failure to recognize the problem of seasonal variation in the actual skid resistance of pavements.

The most comprehensive data bank on seasonal variations has been developed by the Pennsylvania Department of Transportation (DOT) in the course of evaluating the relationship of different aggregates with the skid resistance of asphalt pavements. A detailed study of a series of test strips was made with skid measurements conducted at frequent intervals (1–2 months) over a 4–5 year period. There were 11 test sites throughout the State with 77 different aggregate combinations in a standard high-type, dense-graded asphalt concrete, each combination being duplicated for a total of 154 individual test strips. (3)

During the last 3 years of the experiment (1971–1973) measurements were made at more frequent intervals (minimum of five tests per year) than in earlier years and thus provided greater ranges in skid numbers (SN). For these years, the average seasonal change for the 77 duplicate test strips ranged from 10 SN to 26 SN with an overall average of 14 SN. It is probably significant that the largest changes were found at the site with the highest average daily traffic (ADT), and the smallest changes at the site with the lowest ADT, but this trend was not evident for the intermediate ADT levels. There is, of course, no assurance that these data encompassed the extreme high or low values for a given year since the timing of the periodic monthly tests was dependent upon weather conditions and equipment availability. (These data did not include temperature corrections, because it was found that such corrections made the data more extreme and erratic.)

Minimum skid numbers were found during each of the 10 months (March–December) when tests were conducted although the majority were observed in August and September. The severe winter months (December, January, and February) usually brought about restorative effects although these were variable and in some instances negative. Nevertheless, the overall rejuvenating effects tended to offset the polishing effects in that the plotted curves of skid numbers for the last 3 years showed no consistent upward or downward trends for the annual minimum levels.

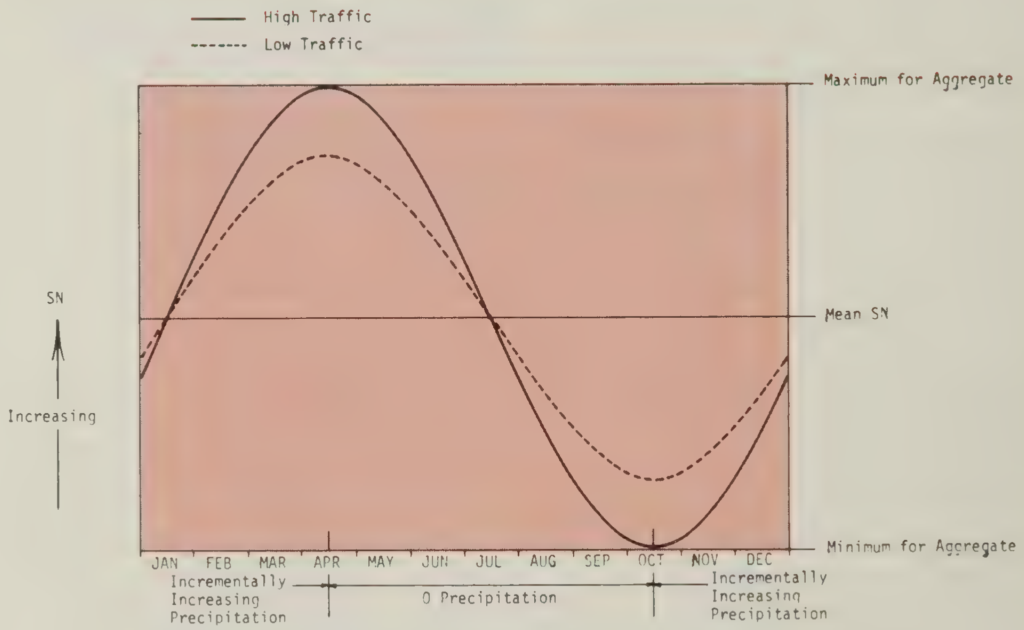


Figure 2.—"Ideal Model"—Annual cycle pavement SN change. (3)

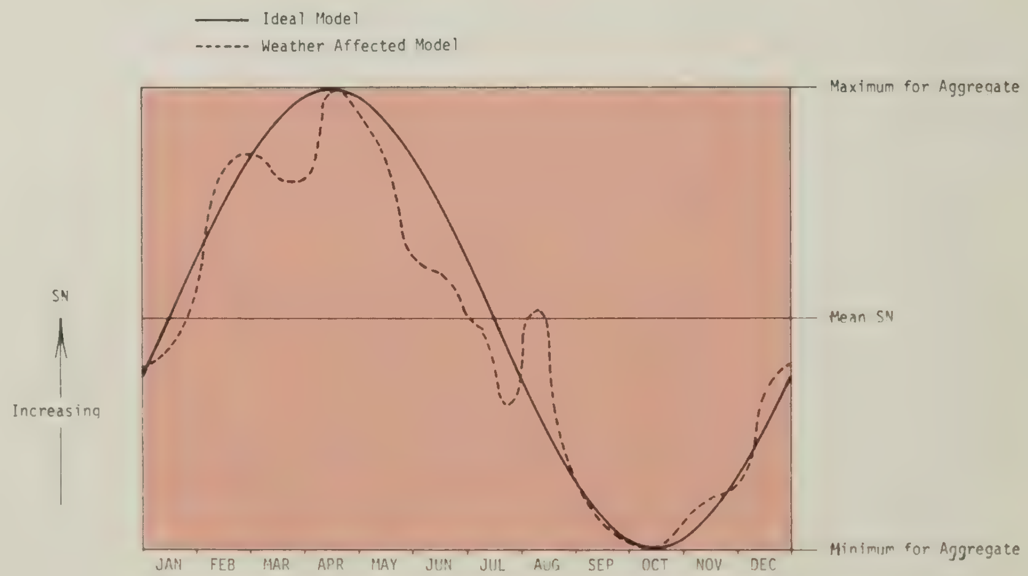


Figure 3.—Annual cycle pavement SN change. (3)

The Pennsylvania DOT researchers proposed an idealized model, as shown in figure 2, based on the assumptions of a smooth temperature variation, incrementally increasing rainfall occurrence during the winter-spring portion of the year, and no precipitation during the summer-fall season. Figure 3 shows an adjustment of the idealized curve to account for the effects of intermittent rainfall. The rejuvenating effects of precipitation are shown in detail for one test strip for a 2-month period in figure 4. (*4*) This figure shows that the magnitude of the intermittent changes in skid number can be as large as 15 SN.

Reports from other States have also included comments on seasonal variations. Some of their quantitative findings are given below

- **Arizona's** tests with a Mu-meter[3] over 8 miles (12.9 km) of portland cement concrete (PCC) highway gave average readings ranging from 33 in September to 56 in January and then down to 32 in May. An analysis of temperature and rainfall data did not satisfactorily explain the phenomenon. (*5*)

- **Connecticut** has conducted monthly tests on portions of high volume roads over a 4-year period. For asphalt surfaces, seasonal variations as high as 15 SN were observed with low points being reached in July and August as compared to early spring and late fall. The plotted data tend to form sine curves as proposed by the Pennsylvania DOT, but the primary cause is attributed to development of contaminating films deposited during the high traffic summer months. High volumes of truck traffic deposit oily contaminations which blacken and soften blacktop surfaces. As traffic volume is reduced, weather removes films. For PCC surfaces, high polish and fairly low skid numbers were found in early spring, with the possible causes being the use of sand and snowplows during winter months. (*6*)

- **Illinois**' test results in spring or early summer for an asphalt surface were higher than in fall by 5 to 10 SN. This is attributed to roughening and cleansing of the surface during winter months when abrasives are used for ice control. Contamination by heavy truck traffic leaves less chance for weathering to cleanse the surface. (*7*)

- **Kansas** has measured seasonal variation as high as 30 skid numbers on one asphalt surface, and in two instances flushing, cooling rains were followed by increases of 14 skid numbers. Considerable variations were found throughout the year with higher SN values usually in early spring and late fall. (*8*)

- **Kentucky**, over a 3-year period of monitoring experimental sand-asphalts, found major variations (in the order of 10 SN) associated with seasonal changes. SN values were lowest during the fall and highest in late winter and spring. (*9*)

- **Louisiana** has not observed any trends associated with seasons—cold, mild, or hot.[4]

- **Missouri** tested several special PCC and asphalt surfaces at approximately 3-month intervals over a 2- to 3-year period. The maximum annual decreases in *coefficient* of friction from spring to fall were 0.10 for PCC surfaces and 0.17 for asphalt surfaces. (*10*)

- **Texas**' study of four aggregate types in surface treatments showed average seasonal decreases—winter to summer—of approximately 10 skid numbers. The report includes a "polishing theory" based on grit size in relation to rainfall, but does not include weathering or chemical actions. (*11*)

- **West Virginia** has observed seasonal changes on experimental asphalt test

[3] A Mu-meter is a trailer for measuring side-force friction.

[4] Unpublished data provided by the Louisiana Department of Highways, Nov. 10 1975.

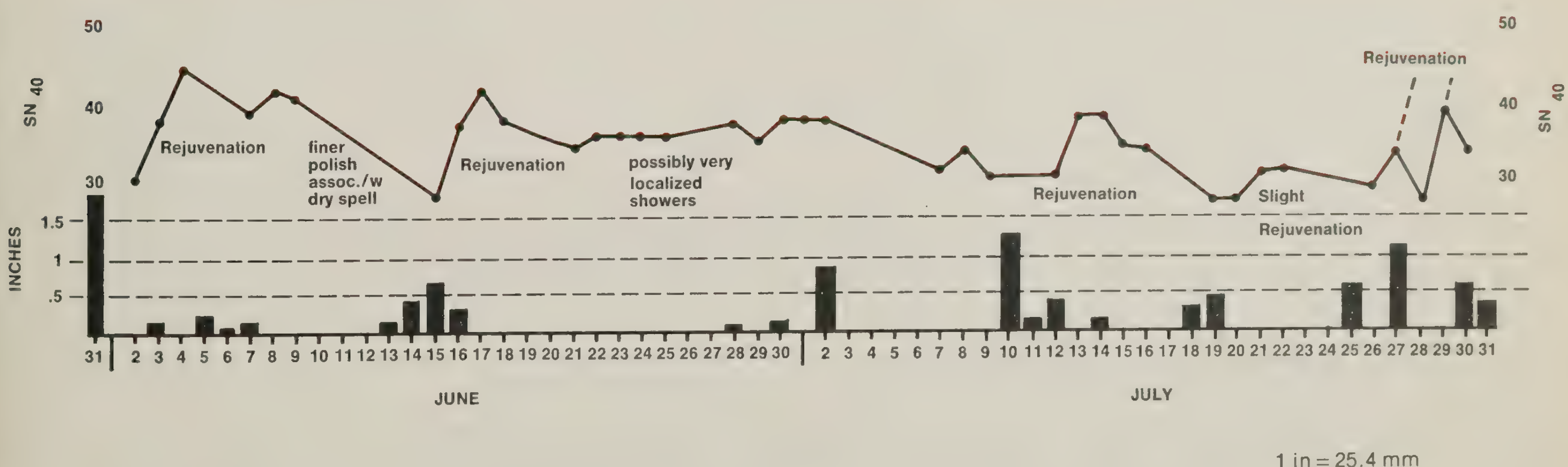


Figure 4.—Influence of precipitation on skid resistance.

strips over a 3-year period. The averaged data showed reductions from May to October of 14 SN and increases from December to May of 10 SN. (*12*)

Mechanisms of Pavement Surface Changes

The mechanisms involved in the wearing and polishing of aggregates and pavement surfaces are complex and vary with different types of aggregates and pavement surfacing systems. In this article, *polishing* is considered to be the loss of microtexture (asperities less than 0.5 mm) and *wearing* is loss of macrotexture (asperities greater than 0.5 mm). Aggregate particles exposed at the pavement surface individually wear and polish, and the overall pavement surface undergoes changes in topography; that is, smoothing due to flushing of asphalt to surface, or rutting due to wear or consolidation in the wheel paths.

It is generally accepted that aggregate particles (and pavement surfaces) must undergo some attrition or surface renewal in order to retain adequate friction. A problem with many naturally occurring aggregates (particularly carbonate rocks which are widely used where available) is that they are composed of fine-grained minerals which are tightly bonded and uniform in hardness. Therefore, abrasion is even which results in polishing of exposed surfaces and in wear, depending on hardness. Other rocks (like some sandstones) are composed of minerals with coarse angular grains, variable hardness, and relatively weak bonding. Abrasion takes place differentially and there is dislodgment of individual grains before the exposed surface becomes polished, although the wear of the surface may be excessive. Similarly, manufactured synthetic aggregates such as expanded clays and shales have a bleb or vesicular structure which does not polish but is susceptible to wear.

The principal mechanisms involved in the textural changes of the aggregates exposed at the pavement surface are abrasion, polishing, differential wear, and weathering (which can also be differential). These mechanisms can also be affected by contaminations of oil, drippings, detritus, and other factors. The finer the detritus or grit on the surface, the higher the degree of polish and loss of microtexture. Presumably, long, dry spells result in finer grit. Rainfall then flushes off the finer grit but may leave coarser grit which under traffic results in roughening and restoration of microtexture. Rainfall can also assist in the removal of oily traffic films although these films may be so heavy as to retard the cleansing action. Carbonic acid precipitated from the atmosphere with rainfall can cause dissolution and leaching or alteration of exposed minerals. Another weathering mechanism is the oxidation and embrittlement of exposed asphalt. The surface films of asphalt are then susceptible to erosion which, with associated loss of fine particles, exposes unworn aggregate surfaces and increases the asperity height of coarse particles.

In many areas of the country, winter conditions bring about reductions in traffic density (less polishing) and wetter and more severe weathering conditions (more roughening both on micro and macro levels). Freezing and thawing of wet surfaces can cause disruption and degradation of unsound aggregate particles and scaling of weak or unsound portland cement concrete. Sand applied to improve traction under snow or ice conditions acts as a coarse abrasive to remove polish (increase in microtexture). Studded-tire wear, at a moderate level, may produce a loss of mortar or matrix between coarse aggregate particles (increase in macrotexture). The blades of snowplows can dislodge fine particles and plane down textured surfaces of portland cement concrete. The use of deicing chemicals (chlorides) can cause the scaling of non-air entrained concrete, but air entrained concrete and asphalt surfaces are not affected either physically or chemically. In consideration of the observations presented previously and depending on the severity of winter conditions, it is concluded that the mechanisms in action during winter months do, in general, effect improvements in pavement surface frictional characteristics.

Consequences of Seasonal Changes

If wet pavement frictional characteristics do change with the seasons and intermittently during the seasons, some of the possible consequences should be considered.

Effect on wet weather accident rates

It is generally accepted that the occurrence of wet weather accidents increases with lower levels of skid resistance. Figure 5 shows that a decrease of 10 SN from 40 to 30 would increase the proportion of wet pavement accidents from 0.28 to 0.44, or 57 percent. (Note that if wet weather conditions were not contributory to accidents, the value would reflect the proportion of wet pavement time—about 0.12 for these data.)

Investigations of skidding accidents

A major function of many skid measurement systems is for the after-the-fact investigation of the frictional characteristics at the site of an accident to determine if the skid resistance level might have been a contributing factor. The time of such measurement could be several months after the accident occurs; thus, the single value determined would be relevant only for the period of the test itself, unless there were some means for adjusting this value to conditions at the time of accident.

Identification of skid-prone locations

In implementing the requirements of the Federal Highway Safety Program Standard 12 (*14*) the Federal Highway Administration (FHWA) Skid Accident Reduction Program (*15*) indicates the need for systematic procedures to identify and correct hazardous skid-prone locations, including the correlation of accident experience with highway data such as measurement of pavement frictional characteristics at particular locations. Such correlations would be confounded if the skid resistance measurements fail to identify hazardous conditions at skid-prone locations due to the occurrence of intermittent or seasonal increases in pavement frictional characteristics.

Statewide inventories of skid resistance measurements

The establishment and maintenance, on a continuing basis, of statewide inventories of skid resistance measurements is also required in response to Highway Safety Program Standard 12. To be most meaningful, such inventories should be conducted so as to detect the minimum levels of skid resistance which will exist when there is a likelihood for rainfall and wet pavement conditions. But with testing priorities being given to accident investigations and identification of hazardous skid-prone locations, the general inventory work may have to be conducted with test vehicles and crews on an as-available basis rather than at the time of lowest skid resistance.

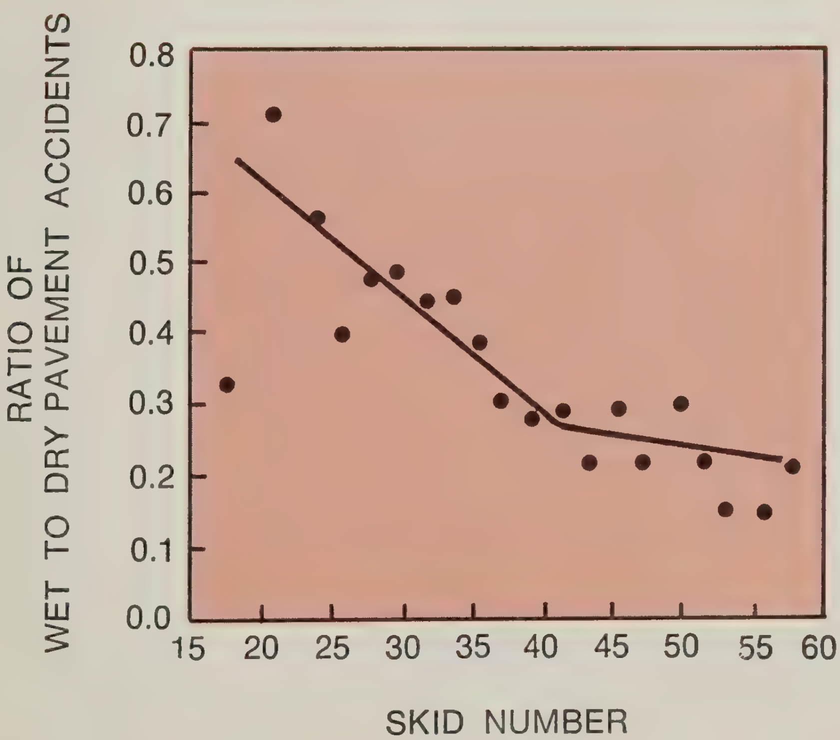


Figure 5.—Ratio of wet to dry pavement accidents of 230 test sections in Kentucky— grouped by skid number—versus skid number. (13)

Evaluation of design, construction, and maintenance practices

Another requirement in response to Standard 12 concerns the evaluation of current pavement design, construction, and maintenance practices. Insofar as these evaluations involve determinations based on measurements of skid resistance, they could well be confused by seasonal or intermittent changes in the intrinsic pavement frictional characteristics. Measurements made in early spring or late fall could be very misleading as to the adequacy of skid resistance properties of any given surface.

Correlations of preevaluation methods with performance

Several procedures are being used to preevaluate aggregates and materials systems in order to insure the selection and design of surfacing mixtures capable of providing adequate skid resistance properties. Accelerated wear/polish devices are useful for ranking materials with respect to susceptibility to wearing and polishing for any given test conditions, but they cannot accurately predict the effect of the actual anticipated traffic in combination with weathering effects unless supplemented with field performance correlations. As noted above, such correlations can be misleading unless based on measurements which account for minimum seasonal levels.

Skid resistance measurement systems

The FHWA Skid Measurement Guidelines for the Skid Accident Reduction Program (*16*) recommend selection and frequent testing of control surfaces as a means of detecting possible erratic performance of the measurement system. If these control surfaces experience unpredictable seasonal and intermittent changes in friction levels, the performance of the measurement system may be wrongly suspected.

Approach to Solution

In recognition of the problem of seasonal variations and the need for a general solution, FHWA has issued a bulletin to (1) encourage States to initiate studies to develop new data covering varying geographic and climatic differences, and (2) propose analysis of existing and new data using advanced statistical methods. (*17*) The collection and analysis of the results are to be coordinated by means of an FHWA administrative contract. A major objective will be the development and validation of a generalized model for predicting minimum pavement skid resistance from measurements taken at any time during the year. Another objective will be a better understanding of the causes and mechanisms of seasonal and intermittent changes which, in turn, should facilitate their control through improved design, construction, and maintenance practices.

REFERENCES

(*1*) C. G. Giles and B. E. Sabey, "A Note on the Problem of 'Seasonal Variation' in Skid Resistance," Proceedings, *First International Skid Prevention Conference, Part II,* Charlottesville, Va., 1959.

(*2*) W. H. Goetz and J. M. Rice, "Factors Affecting the Measurement of Skid Resistance," Proceedings, *First International Skid Prevention Conference, Part I,* Charlottesville, Va., 1959.

(*3*) W. L. Gramling and J. G. Hopkins, III, "Skid Resistance Studies: Aggregate-Skid Resistance Relationship as Applied to Pennsylvania Aggregates, " Final Report No. 65–4, *BMTR, Pennsylvania Department of Transportation,* May 1974.

(*4*) M. A. Furbish and K. E. Styles, "Relationship of Skid Resistance to Petrography of Aggregates," Final Report Study 68–22, *BMTR, Pennsylvania Department of Transportation,* July 1972.

(*5*) J. C. Burns and R. J. Peters, "Surface Friction Study of Arizona Highways," Final Report HPR–1–9(162), *Materials Division, Arizona Highway Department,* August 1972.

(*6*) G. A. Ganung, "Frictional Characteristics of Paving Materials in Connecticut," Reports 1, 2, and Final, Research Project HPR–356, *Connecticut Department of Transportation,* April 1973, August 1974, and May 1975.

(*7*) P. G. Dierstein, P. F. Ryan, and W. C. Purcell, "Skid-Resistant Characteristics of Experimental Bituminous Surfaces in Illinois," Physical Research Report No. 44, *Illinois Department of Transportation,* February 1973.

(*8*) H. E. Worley, T. M. Methany, and F. W. Stratton, "Pavement Surface Dynamics Friction Measurement and Analysis in Kansas," Final Report FHWA–KS–RD–73–3, *Kansas Department of Transportation,* June 1976.

(*9*) R. L. Rizenbergs, J. L. Burchett, and C. T. Napier, "Skid Resistance of Pavements," Interim Report KYHPR–64–24, *Kentucky Department of Highways,* July 1972.

(*10*) "An Investigation of Skid Resistance in Missouri," Final Report MCHRP–73–3, *Missouri State Highway Department,* August 1973.

(*11*) J. R. Underwood, K. D. Hankins, and E. Garana, "Aggregate Polishing Characteristics: The British Wheel Test and the Insoluble Residue Test," Research Report 126–2, *Texas Highway Department,* January 1971.

(*12*) J. R. O'Leary and R. G. Ward, "Road Test Research for Skid Resistant Bituminous Surfaces," Final Report Research Project 35, *West Virginia Department of Highways,* December 1975.

(*13*) R. L. Rizenbergs, J. L. Burchett, and L. A. Warren, "Accidents on Rural, Two-Lane Roads and Their Relation to Pavement Friction," Report No. 443, *Kentucky Department of Transportation,* April 1976.

(*14*) "Highway Design, Construction, and Maintenance," subch. B, ch. II, Highway Safety Program Standards, *U.S. Department of Transportation*, Washington, D.C., February 1974.

(*15*) "Skid Accident Reduction Program," Instructional Memorandum 21–2–73, *Federal Highway Administration,* Washington, D.C., July 1973.

(*16*) "Skid Measurement Guidelines for the Skid Accident Reduction Program," vol. 6, ch. 2, sec. 4, subsec 7, Federal-Aid Highway Program Manual, *Federal Highway Administration,* Washington, D.C., December 1975.

(*17*) "Research on Seasonal Variations of Pavement Skid Resistance," FHWA Bulletin, *Federal Highway Administration,* Washington, D.C., March 1976.

Our Authors

Janet Coleman is a mathematician in the Traffic Systems Division, Office of Research, Federal Highway Administration. She has been with FHWA since 1971 and is project manager for FCP Project 1O "Aids to Surveillance and Control: Railroad-Highway Grade Crossings." Ms. Coleman is currently responsible for research studies concerned with improved signing and signals for railroad-highway grade crossings, grade crossing accident analysis, illumination for grade crossings, and off-track train detection and warning devices.

Joseph S. Koziol, Jr., is a general engineer in the Traffic Control Systems Division, Office of Systems Development, Transportation Systems Center. He presently is working on Federal Highway Administration sponsored programs and is responsible for the specification, development, test, and evaluation of innovative traffic control systems and devices for improving highway efficiency, safety, and capacity. Before joining Transportation Systems Center in 1970, Mr. Koziol was with the NASA Electronics Research Center.

Peter H. Mengert is a mathematician in the Information Sciences Division, Office of Engineering, Transportation Systems Center. He works in the area of computer analysis and statistics and has published several research papers in this field. Prior to 1969, Dr. Mengert was with the NASA Electronics Research Center and with Honeywell, Inc., in the fields of computer and statistical analysis and pattern recognition.

Charles Philip Brinkman is a physicist in the Environmental Design and Control Division, Office of Research, Federal Highway Administration. He is involved in the research of ice and snow control and skid reduction. Mr. Brinkman is also working with the Federal Highway Administration Coordinating Task Force on Metrication.

James H. Sanders is a senior engineer and head of the Instrumentation and Data Analysis Group, BioTechnology, Inc., which provides instrumentation and automatic data processing in support of BioTechnology's research activities. He joined BioTechnology, Inc., in 1969 and has directed projects of the Products Division, which includes the design and development of training devices and human performance testing systems. He has also directed several projects for the Federal Highway Administration, the National Highway Traffic Safety Administration, and the Federal Railroad Administration involving rail-highway intersection safety.

Wallace G. Berger is a Professional Staff Member of the Appropriations Committee of the U.S. Senate. His activities on the committee center on evaluating the budget requests of the U.S. Department of Transportation and its related agencies. From 1972 to 1975, Dr. Berger was Chief Scientist and Director of the Transportation Department at BioTechnology, Inc. Prior to this, he directed projects in human factors and highway safety at Serendipity, Inc., and the University of Michigan.

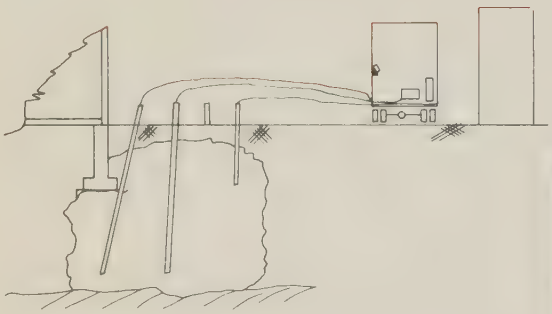
Fred R. Hanscom is a senior engineer at BioTechnology, Inc. In addition, he participates in professional society committee activity in both the Transportation Research Board and the Institute for Traffic Engineers. Mr. Hanscom's work has dealt with the evaluation of new traffic control devices, countermeasures for pedestrian accidents, and highway sites with high-skid potential.

William C. Besselievre is a highway engineer in the Implementation Division, Office of Development, Federal Highway Administration. Before joining FHWA in 1973, his engineering experience included the following: engineering supervisor and inspector on construction of radar-radio telescope, Arecibo, P.R.; exclusive surveyor for American Bureau of Shipping, New York, N.Y.; construction inspector of a seaplane base and parking garage, New York, N.Y.; general design for a consultant firm, New York, N.Y.; party chief of surveying party, Long Island, N.Y.; and construction engineer, design engineer, maintenance engineer, engineering planner, and specification writer while an officer in the U.S. Air Force.

James M. Rice has been a research engineer in the Materials Division, Office of Research, Federal Highway Administration, since 1962. His career in the asphalt paving field spans over 25 years and includes employment with the National Crushed Stone Association and the Natural Rubber Bureau. His current research efforts are directed toward the mechanical properties of asphalt paving mixtures and the skid resistance and wear resistance of pavement surfaces.

Recent Research Reports

The following are brief descriptions of selected reports recently published by the Office of Research, Federal Highway Administration, which includes the Structures and Applied Mechanics Division, Materials Division, Traffic Systems Division, and Environmental Design and Control Division. The reports are available from the address noted at the end of each description.



Grouting in Soils, Volume 1—A State-of-the-Art Report (Report No. FHWA-RD-76-26) and Volume 2—Design and Operations Manual (Report No. FHWA-RD-76-27)

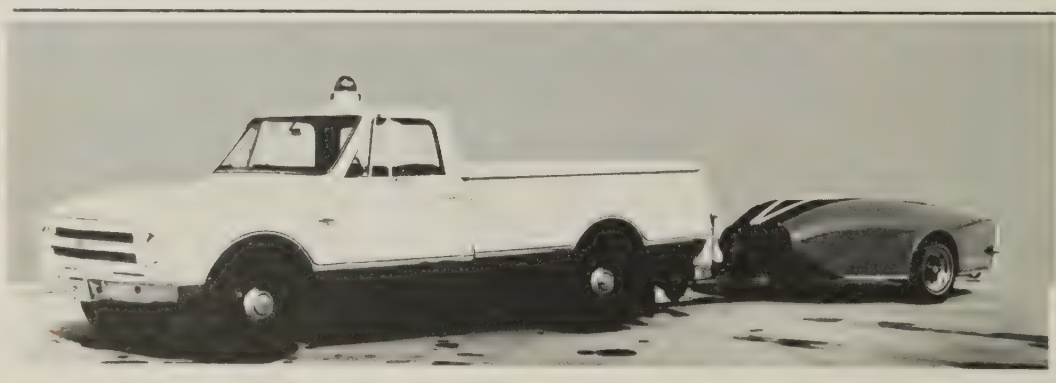
by FHWA Structures and Applied Mechanics Division

Among the many problems encountered in excavating for transportation tunnels are the intrusion of water and the movement of adjacent ground into the excavation. A useful technique in solving such problems is injecting the formation to be excavated with a fluid grout material which hardens to reduce water movement or to consolidate and strengthen the formation.

Volume 1 of this report presents the current state of the art of all aspects of grouting technology applicable to soils from theory to field practices. Particular emphasis is given to soft-ground tunneling and to cut-and-cover construction.

Volume 2 presents the best current soil grouting practices, guides for the design of grouting injection patterns, injection control methods, and the evaluation of the completed treatments. Among the items described are (1) how to select the proper grout material, (2) planning for the execution of the job, and (3) the preparation of plans and specifications for a grouting project. The report also discusses the three general grouting techniques (permeation, void filling, and compaction) and covers in detail six applications: groundwater control, sand stabilization, soil strengthening, backpacking tunnel liners, leak repairs, and tieback anchorage.

Both volumes of the report are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Vol. 1—Stock No. PB 259043; Vol. 2—Stock No. PB 259044).



Pavement Surface Dynamics Friction Measurement and Analysis in Kansas, Report No. FHWA-KS-RD-73-3

by Kansas Department of Transportation for FHWA Materials Division

This report evaluates combinations of pavement surface materials with construction and maintenance practices to determine which will produce the highest practicable skid resistance values under varying environmental conditions throughout Kansas. Friction measurements of numerous pavement surfaces were made with a locked-wheel skid trailer. Tests show that skid numbers are not constant for a given section of roadway or type of construction. Seasonal variation of 30 skid numbers has been measured in Kansas indicating that a single value is not representative of yearlong conditions. Some combinations of materials and types of pavements indicate possible superiority, such as chert (chat) aggregate used in portland cement concrete pavement and slurry seals, but not in hot mixes. Expanded shale and sandstone are shown to be good skid resistant aggregates.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 255490).

You Should Know About

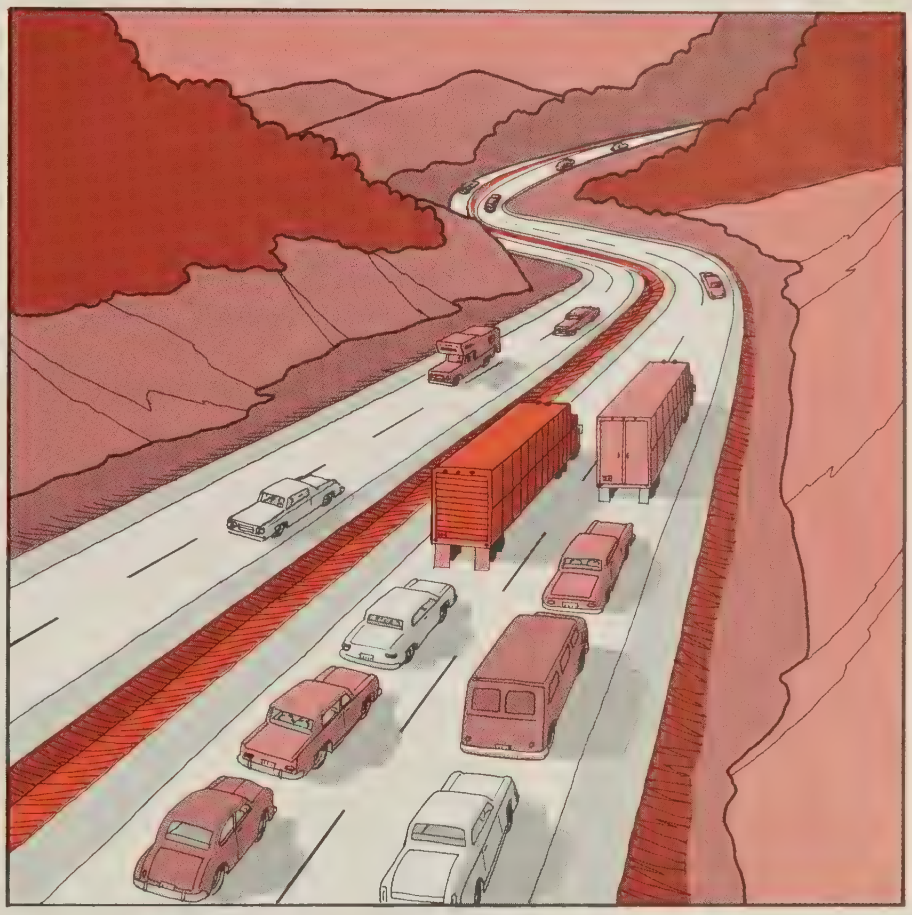
Review of Current and Proposed Low Cost Freeway Incident Management Systems, Report No. FHWA–RD–76–111

by FHWA Traffic Systems Division

The purpose of this interim report is to present the current state of the art in freeway incident management. Present practices used by operating agencies in detecting and responding to freeway incidents are presented. Candidate surveillance and detection methods are discussed in terms of the detection, administrative, organizational, preplanning, and traffic control options of each. Major emphasis is placed on low cost, minimum investment systems which do not require large, extensive computer surveillance and control systems or long periods of time for implementation.

The final report, which will be available after July 1977, will present guidelines and recommendations on how operating agencies can select and implement alternative surveillance, detection, and response methods for freeway incident management.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 259007).



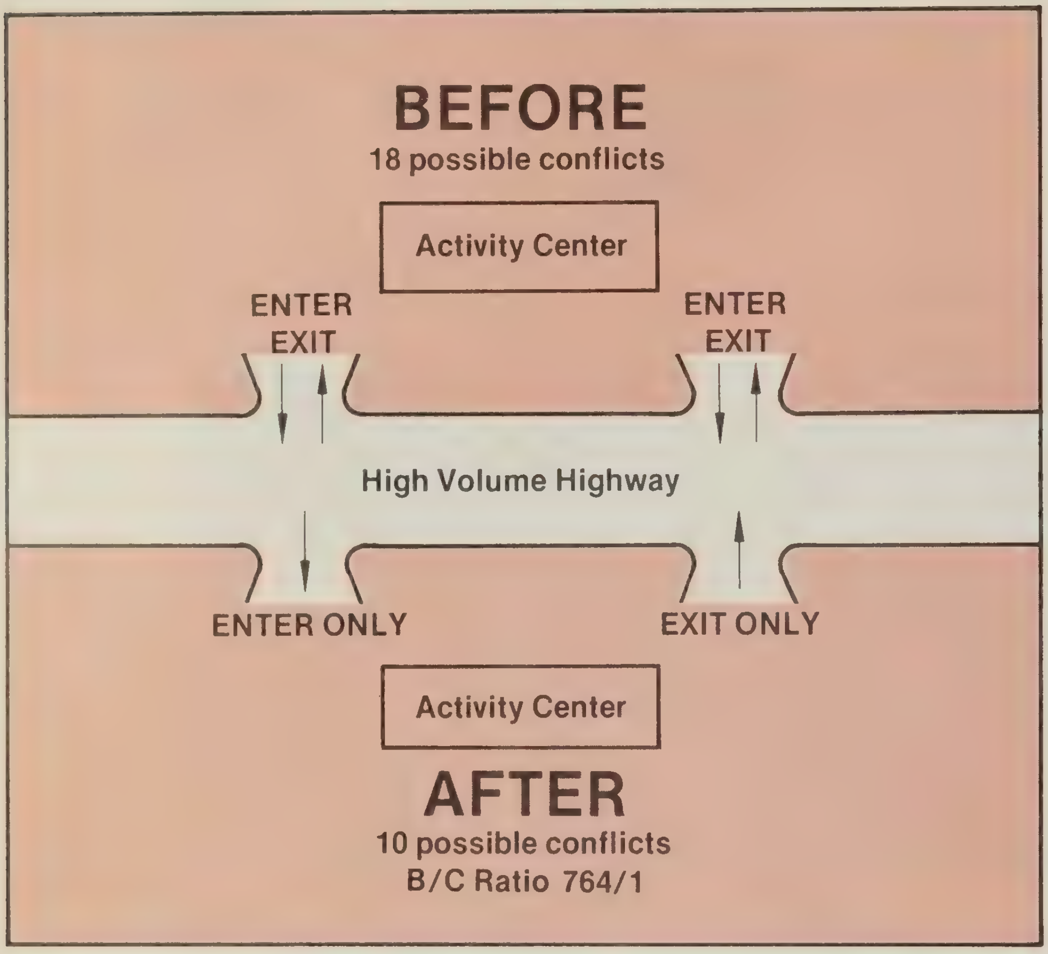
Freeway Design and Control Strategies as Affected by Trucks and Traffic Regulations, Report No. FHWA–RD–75–42

by FHWA Traffic Systems Division

This final report is the culmination of several contract efforts which have led to the development of design guidelines for determining equivalent levels of service for mixed commercial and passenger vehicular flows on various grades for freeways. The project described in the report used data collected on freeway grades in rolling and mountainous terrain for simulation model development and validation. The simulation model was then used to develop the design charts.

The design guidelines should help operational and design personnel determine the effects of adding a lane to a freeway where there are grade-induced traffic problems. The effects of adding a climbing lane can also be determined. Finally, the design guidelines can be a useful tool in setting priorities for addition of new lanes to major freeway routes in rolling and mountainous terrain.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 245033).



Control of Access and Egress on Unlimited Access Facilities: Evaluation of the Traffic Conflicts Technique (Report No. FHWA–RD–76–88) and Evaluation of Techniques for the Control of Direct Access to Arterial Highways (Report No. FHWA–RD–76–85)

by FHWA Environmental Design and Control Division

These two reports document ways to control access and egress on unlimited access facilities. The first report is an evaluation of the traffic conflict method for estimating the relative safety of a highway location without having to wait for an accident history to develop. Although some studies indicate that the traffic conflicts method is a reliable tool to predict accident potential, the evaluation found a more rigorous data base is needed to assure reliability.

The second report documents the evaluation of 70 techniques for controlling access. Analysis of low cost techniques, such as conversion to one-way traffic operation on highway and access roads, shows that they yield very high benefit-to-cost ratios. Substitution of one-way (rather than two-way) driveways to activity centers was highly cost effective for high volume roads. A more costly technique, raised medians with left turn bays, showed the greatest potential for overall accident reduction.

Both reports are available from the Environmental Design and Control Division, HRS–40, Federal Highway Administration, Washington, D.C. 20590.

A State-of-the-Art Report on Roadway Delineation Systems, Report No. FHWA–RD–76–73

by FHWA Environmental Design and Control Division

Roadway delineation treatments and systems are those devices and techniques which provide guidance, regulatory, or warning information to drivers under various highway situations. This report represents the first phase of a large-scale research program aimed at improving the utilization of roadway delineation.

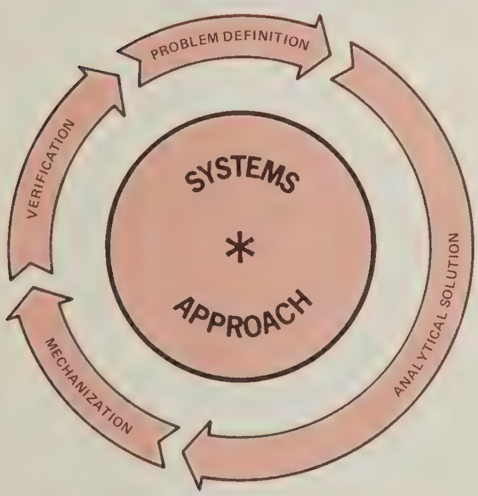
The report includes a review of studies on the application of different treatments and systems for various highway situations, and constitutes an update to National Cooperative Highway Research Program Report 130. Materials, cost, maintenance, durability, and environmental effects are also considered. Preliminary recommendations subject to ongoing research are contained in the report along with a partially annotated bibliography.

The report is available from the Environmental Design and Control Division, HRS–40, Federal Highway Administration, Washington, D.C. 20590.

Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items which have been recently completed by State and Federal highway units in cooperation with the Implementation Division, Offices of Research and Development, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies. These items will be available from the Implementation Division unless otherwise indicated.

U.S. Department of Transportation
Federal Highway Administration
Office of Development
Implementation Division, HDV-20
Washington, D.C. 20590



Traffic Control Systems Handbook, Implementation Package 76-10

by FHWA Implementation Division

Present day urban traffic problems have created an urgent need for the development of both basic and advanced transportation and traffic engineering resources. This handbook presents the basic principles for the planning, design, and implementation of traffic control systems for urban streets and freeways. Individual elements discussed include traffic control studies and concepts, surveillance techniques, street hardware, central equipment and system selection, and implementation and evaluation methods.

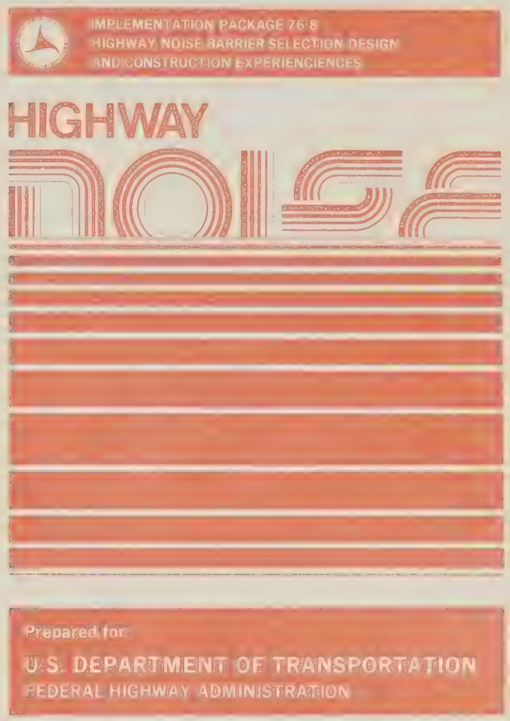
The handbook was developed for a wide range of potential users, but it is primarily aimed at the practicing traffic engineer who has had limited exposure to computer-based systems. Its objective is to aid in the application of new technology in the implementation of traffic surveillance and control systems. The use of the handbook with other proven and newly emerging transportation system management concepts will help make better use of existing facilities.

The handbook is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00114-4). State, city, and municipal engineers involved in traffic control systems may obtain a free copy by sending a request with a self-addressed mailing label to the Implementation Division.

Highway Noise Barrier Selection, Design, and Construction Experiences: A State-of-the-Art Report—1975, Implementation Package 76-8

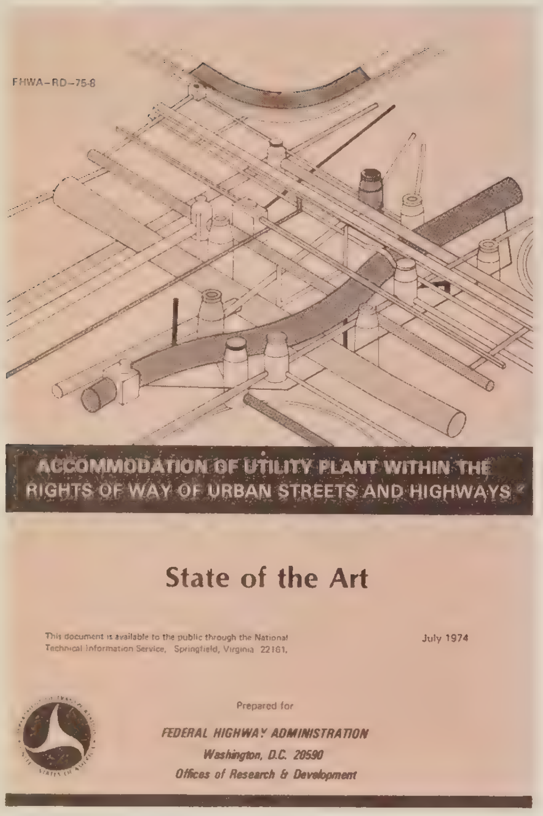
by FHWA Region 10

Highway engineers are becoming increasingly aware of the wide range of alternatives that are available to abate



highway traffic noise. One of the most commonly used alternatives has been the construction of free standing noise barriers. This report contains a cross section of the experiences of State highway agencies in the selection, design, and construction of highway noise barriers. It summarizes progress to date and includes project data, sample plans, and photographs for different types of barriers. Factors considered in the report include safety, barrier design, cost, attenuation, community acceptance, and maintenance problems.

The report is available from the Implementation Division.



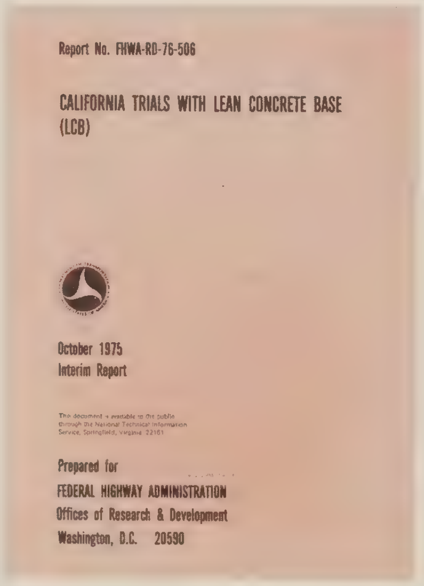
Accommodation of Utility Plant Within the Rights-of-Way of Urban Streets and Highways: State of the Art (Report No. FHWA–RD–75–8) and Manual of Improved Practice (FHWA–RD–75–9)

by FHWA Environmental Design and Control Division

The State of the Art report presents technological background and factual practice on which agencies can build an effective, workable utility location program. The study points out that actual constraints, other than physical space, are not great for any one utility; but finite urban space and the needs of expanding utilities have created many problems. As a result, only gradual improvement in older areas can be expected. However, in new and redeveloped areas steps can be taken now to minimize future problems.

The Manual of Improved Practice sets forth principles and practices under which utility facilities can be successfully accommodated within urban rights-of-way. It covers the following subject areas: planning and records; applications and permits; inspection; trench openings and restorations; traffic control; subsurface damage prevention; engineering safety standards, installation, and maintenance; traffic needs; location considerations and constraints; and economic analysis of utility location alternatives.

The reports are available from the Implementation Division or the Federal Aid Division, HNG–14, Office of Engineering, Federal Highway Administration, Washington, D.C. 20590.

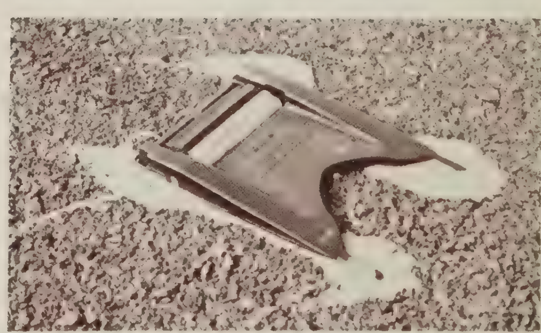


California Trials with Lean Concrete Base (LCB), Report No. FHWA–RD–76–506

by FHWA Implementation Division

This report describes California's experience with lean concrete base (LCB). It covers details of two large-scale field trials. By adding additional cement and water to aggregates used for cement treated base (CTB), a plastic mix is produced which can be placed with a slipform paver using only internal vibration for compaction. Between 50 and 100 percent additional cement was required to produce LCB with compressive strength comparable to the in-place strength of CTB. LCB was found to have greater stiffness and a more sealed and abrasion resistant surface than CTB. Some of the increased costs due to the additional cement are offset by greater production and the possible use of less construction equipment.

The report is available from the Construction and Maintenance Division, HHO–31, Office of Highway Operations, Federal Highway Administration, Washington, D.C. 20590.



Snowplowable Raised Pavement Markers

by New Jersey Department of Transportation for FHWA Implementation Division

The New Jersey Department of Transportation has developed a 13-minute slide-tape program highlighting their development and field trials of a snowplowable raised pavement marker known as the Stimsonite 99. This presentation was produced as part of a Highway Planning and Research (HP&R) evaluation study and suggests the application of this delineation treatment in areas of light-to-moderate snowfall. The marker is encased in a hardened steel casting and is capable of withstanding the damaging impact of steel snowplow blades. However, considerable damage results when tungsten carbide blades are used. Projected cost estimates show that over a 10-year period, the Stimsonite 99's will more than double the cost of a delineation program—a price one must consider when choosing alternatives for an all-weather delineation system.

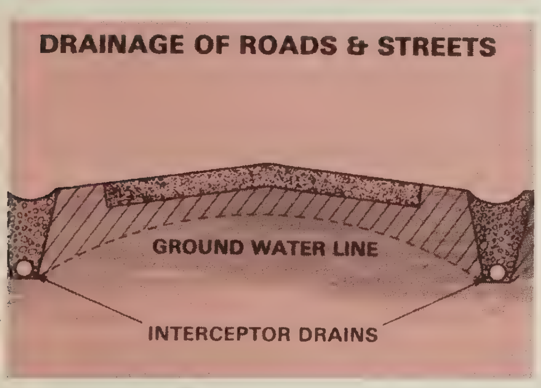
The slide-tape program is available from FHWA regional offices (see p. 155).

Two-Course Concrete Systems

by Oklahoma Highway Department

This color video tape, prepared by the Oklahoma Highway Department, serves a dual purpose. First, it visually shows how Oklahoma is addressing the bridge deck deterioration problem by focusing on two bridge deck overlay systems, the Dow and Iowa systems. Second, it is an excellent example of how this media can be used to transfer general information and be used as a quality control training tool. Oklahoma has also used a public relations oriented edition of the tape for viewing by local public interest groups.

The video tape is available from FHWA regional offices (see p. 155).



Water-in-Pavements

by FHWA Implementation Division

The fact that water under a pavement can substantially reduce its performance life was brought out in the 1973 series of Water-in-Pavements Workshops. As a result of those workshops, a 20-minute slide-tape presentation was prepared which traces the history of early design approaches, including shortcomings, through present day knowledge and practice. It is recommended that the need for improved pavement drainage, on both existing and new highway projects, be evaluated. If treatment is needed, the level of effort necessary to accomplish this becomes a balance between economic and engineering considerations.

The slide-tape presentation is available from FHWA regional offices (see p.155).

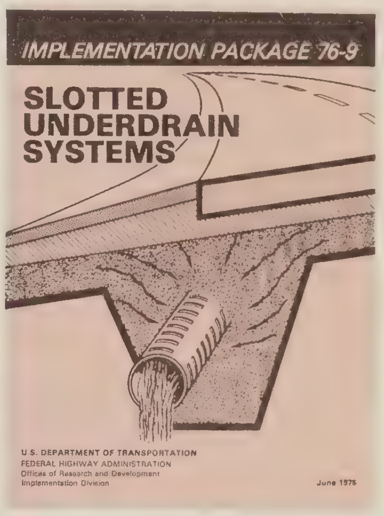
Internally Sealed Concrete

by Oklahoma Highway Department

During December 1975, Oklahoma placed a wax beaded concrete bridge deck. In March 1976 the deck was heat treated to seal off the deck surface. These operations were filmed and a videotape was produced entitled "Internally Sealed Concrete."

In this procedure wax beads are mixed into the plastic concrete. After proper curing, the concrete is heated which causes the wax beads to melt and flow into the capillaries and pores of the concrete. Thus the deck surface is sealed against moisture and chlorides. The videotape shows both the placing of the wax beaded concrete and the heat treating process. The complete procedure is covered in sufficient detail to be of value to any organization interested in the possible use of internally sealed concrete as a solution to the problem of chloride-induced corrosion and deterioration of concrete bridge decks.

The videotape is available from FHWA regional offices (see p. 155).



Slotted Underdrain Systems, Implementation Package 76–9

by FHWA Implementation Division

Slotted plastic pipe has been used in agriculture as an underdrain for many years. Because of the success of this pipe in providing long term drainage, the Federal Highway Administration's Office of Federal Highway Projects in Region 8 undertook an evaluation project to determine the application of these types of underdrains in the highway industry. Their findings, as presented in Implementation Package 76–9, have shown that a properly designed slotted underdrain system is capable of quickly and efficiently removing free water from soils and pavement structures over a long period without clogging the filter system or causing siltation of the pipe.

This report contains test results and findings of six underdrain systems as well as a design example and sample specifications.

The report is available from the Implementation Division.

New Research in Progress

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

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1A: Traffic Engineering Improvements for Safety

Title: Effectiveness of Freeway Lighting. (FCP No. 31A1684)
Objective: Evaluate the safety impact of reduced or newly installed freeway lighting.
Performing Organization: Mark Battle Associates, Washington, D.C. 20036
Expected Completion Date: February 1978
Estimated Cost: $142,000 (FHWA Administrative Contract)

Title: Safety Features of Stop Signs at Rail-Highway Grade Crossings. (FCP No. 31A1704)
Objective: Determine advantages and disadvantages of selective use of stop signs as safety improvements at rail-highway grade crossings and develop recommendations for use or nonuse of standard highway stop signs at public rail-highway grade crossings.
Performing Organization: Bio-Technology, Inc., Falls Church, Va. 22042
Expected Completion Date: December 1977
Estimated Cost: $100,000 (FHWA Administrative Contract)

Title: Safety Evaluation of Priority Techniques for High Occupancy Vehicles. (FCP No. 31A1714)
Objective: Analyze accidents of priority treatment projects for high occupancy vehicles, analyze the liability problem, and develop guidelines for operations to minimize accident potential and for legislation to minimize liability issues.
Performing Organization: Beiswenger Hoch and Associates, North Miami Beach, Fla. 60028
Expected Completion Date: March 1978
Estimated Cost: $124,000 (FHWA Administrative Contract)

FCP Project 1J: Improved Geometric Design

Title: Improving the Traffic Operations and Safety of Ramps and Speed Change Lanes. (FCP No. 31J4022)
Objective: Through a combination of a state-of-the-art evaluation, a development of analytical techniques, and field observations, develop cost-effective procedures and geometric design criteria to plan, design, and construct ramps and speed change lanes and/or modify existing ones at the freeway-arterial highway interchange. A variety of geometric elements, vehicles, and speeds will be included.
Performing Organization: Michael Baker, Jr., Inc., Beaver, Pa. 15009
Expected Completion Date: September 1979
Estimated Cost: $384,000 (FHWA Administrative Contract)

FCP Project 1L: Improving Traffic Operations During Adverse Environmental Conditions

Title: Effectiveness of Reduced Visibility Guidance Techniques. (FCP No. 31L4042)
Objective: Evaluate the impact on traffic safety and operations of alternative hardware and guidance strategies for reduced visibility conditions.
Performing Organization: Sperry Rand Corporation, Great Neck, N.Y. 11020
Expected Completion Date: February 1978
Estimated Cost: $304,000 (FHWA Administrative Contract)

Title: Physical Alternatives to Chemicals for Highway Deicing. (FCP No. 31L9033)
Objective: Develop a practical and economical physical system of highway deicing that will substitute for or minimize the use of sodium chloride, calcium chloride, or other chemicals and will not adversely affect

the environment or the physical integrity and utility of the highway.
Performing Organization: Midwest Research Institute, Kansas City, Mo. 64110
Expected Completion Date: August 1979
Estimated Cost: $231,000 (FHWA Administrative Contract)

FCP Project 1U: Safety Aspects of Increased Size and Weight of Heavy Vehicles

Title: The Effects of Truck Size on Driver Behavior. (FCP No. 31U3642)
Objective: Define car-truck interactions that produce unsafe changes in driver behavior. Through experimentation, ascertain the magnitude and frequency of such changes. Provide remedial techniques to counter such changes. Provide recommendations for maximum permissible truck sizes.
Performing Organization: Institute for Research, State College, Pa. 16801
Expected Completion Date: September 1978
Estimated Cost: $300,000 (FHWA Administrative Contract)

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

FCP Project 2C: Requirements for Alternate Routing to Distribute Traffic Between and Around Cities

Title: Evaluating Urban Freeway Guide Signing. (FCP No. 42C2022)
Objective: Develop a field technique to identify urban freeway guide signing problems and related delineation and geometric problems relevant to navigation. Develop level of service procedures for freeway guide signing, remedial signing treatments, and guidelines for modifying delineation and geometrics.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas Highway Department
Expected Completion Date: August 1978
Estimated Cost: $120,000 (HP&R)

FCP Project 2D: Traffic Control for Coordination of Car Pools and Buses on Urban Freeway Priority Lanes

Title: Preferential Lanes for High Occupancy Vehicles in the Banfield Freeway in Portland, Oreg. (FCP No. 32D1554)
Objective: Measure traffic flows, transit and carpool usage, safety, and air quality effects from the installation and operation of a bus/carpool lane on the Banfield Freeway in Portland, Oreg.
Performing Organization: Oregon State Highway Division, Portland, Oreg. 97213
Expected Completion Date: October 1977
Estimated Cost: $150,000 (FHWA Administrative Contract)

Title: Fringe Parking for Carpool Staging. (FCP No. 32D3504)
Objective: Install fringe parking areas in the San Francisco and Los Angeles areas and measure resulting changes in car occupancy, air quality, energy savings, and public attitude.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95814
Expected Completion Date: February 1978
Estimated Cost: $100,000 (FHWA Administrative Contract)

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

FCP Project 3F: Pollution Reduction and Visual Enhancement

Title: Control and Maintenance of Highway Vegetation. (FCP No. 43F1942)
Objective: Evaluate establishment and persistence of new plant selections, develop minimum cost highway vegetation management programs, and evaluate spray application systems.
Performing Organization: Auburn University, Auburn, Ala. 36830
Funding Agency: Alabama State Highway Department
Expected Completion Date: June 1980
Estimated Cost: $94,000 (HP&R)

Title: Biological Control of Yellow Star Thistle and Field Bindweed Along California Highways. (FCP No. 43F1942)
Objective: Provide for the development and implementation of weed feeding insects, mites, and plant pathogens to reduce the abundance and spread rate of yellow star thistle and field bindweed along highways in California.
Performing Organization: U.S. Department of Agriculture, Albany, Calif. 94706
Expected Completion Date: June 1980
Estimated Cost: $131,000 (HP&R)

Title: Highway Noise Criteria. (FCP No. 33F4502)
Objective: Develop a methodology for assessment of human response to general traffic noise.
Performing Organization: U.S. National Bureau of Standards, Washington, D.C. 20234
Expected Completion Date: September 1979
Estimated Cost: $300,000 (FHWA Administrative Contract)

Title: Application of Acoustical Scale Modeling to Traffic Noise Propagation at Complex Urban/Suburban Freeway Sites. (FCP No. 33F4512)
Objective: Develop a noise prediction procedure for urban and suburban freeway sites using scale modeling techniques.
Performing Organization: Bolt Beranek Newman, Cambridge, Mass. 02138
Expected Completion Date: September 1978
Estimated Cost: $174,000 (FHWA Administrative Contract)

FCP Category 4—Improved Materials Utilization and Durability

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

Title: Development of a Polymer Concrete Overlay Utilizing a Vinyl Ester Polymer. (FCP No. 34B1423)
Objective: Develop a vinyl ester polymer concrete suitable for use as an overlay material and evaluate the material by a number of full-scale field applications.
Performing Organization: U.S. Bureau of Reclamation, Denver, Colo. 80225
Expected Completion Date: December 1978
Estimated Cost: $126,000 (FHWA Administrative Contract)

FCP Project 4C: Use of Waste as Material for Highways

Title: Construction and Evaluation of Kenedy County Sulfur-Asphalt Test Sections. (FCP No. 34C3024)
Objective: Construct and evaluate the design and performance of test pavements using sulfur-asphalt binders.
Performing Organization: Texas Highway Department, Austin, Tex. 78701
Expected Completion Date: October 1979
Estimated Cost: $95,000 (FHWA Administrative Contract)

Title: Production of Highway Construction Materials from Cellulosic and Related Waste. (FCP No. 34C3053)
Objective: Investigate the technical and economic feasibility of producing binder materials from cellulosic and related wastes and develop an appropriate process for their production.
Performing Organization: Suntech Inc. Research and Engineering, Marcus Hook, Pa. 19061
Expected Completion Date: December 1978
Estimated Cost: $252,000 (FHWA Administrative Contract)

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

Title: Airborne Resistivity Techniques for Locating Construction Materials. (FCP No. 34E1132)
Objective: Evaluate airborne resistivity techniques for determining the location and extent of buried, or otherwise masked, granular materials. Evaluate the usefulness of the technique for determining the soil-bedrock interface.
Performing Organization: Earth Satellite Corporation, Washington, D.C. 20015
Expected Completion Date: September 1978
Estimated Cost: $226,000 (FHWA Administrative Contract)

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

FCP Project 5F: Structural Integrity and Life Expectancy of Bridges

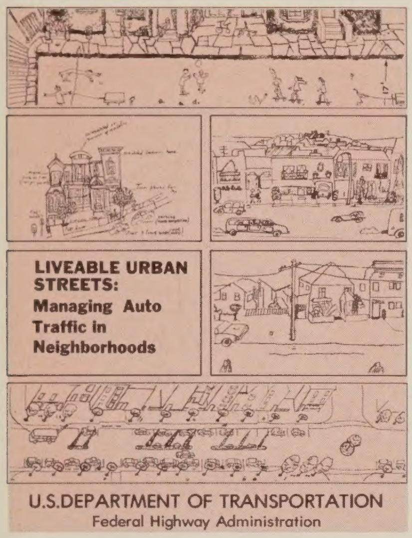
Title: Fracture Toughness, Fatigue, and Corrosion Properties of Steel Butt Joint Weldments. (FCP No. 45F2302)
Objective: Evaluate electroslag and submerged arc butt weldments for their fracture toughness, fatigue, and corrosion properties in two grades of bridge steels.
Performing Organization: Michigan Department of State Highways, Lansing, Mich. 48904
Expected Completion Date: September 1979
Estimated Cost: $220,000 (HP&R)

Non-FCP Category 0—Other New Studies

Title: Design of Drilled Shafts to Support Precast Panel Retaining Walls. (FCP No. 40S8362)
Objective: Develop criteria for the rational design of drilled shafts that support precast panel retaining walls, mainly through the construction, instrumentation, and testing of drilled shafts in a variety of soils.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77840
Funding Agency: Texas Highway Department
Expected Completion Date: August 1979
Estimated Cost: $120,000 (HP&R)

U.S. Government Printing Office: 1977—720-212/1

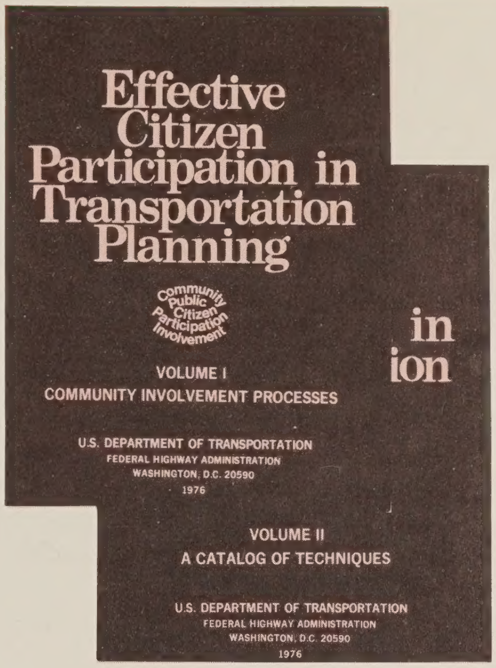
New Publications



Liveable Urban Streets: Managing Auto Traffic in Neighborhoods analyzes the effects that traffic has on street life and on attitudes in residential neighborhoods, and reports efforts that have been made to reduce the severity of these effects. About 500 people who lived on streets with varying amounts of traffic were interviewed at their homes in San Francisco, Calif. Residents of streets with the heaviest traffic (10,000 or more vehicles per day) reported significant problems, especially with traffic noise. The people who live on the streets with lighter traffic are not without traffic-related problems, however. Intermittent speeding cars were seen as the chief hazard. Half the people on the low-traffic streets were disturbed by the danger of traffic to children playing outside.

Traffic problems in residential areas can be minimized through traffic management. This study describes such programs in Great Britain and several other countries as well as recent efforts in San Francisco and Berkeley, Calif. The report concludes that there is significant potential for wider use of traffic management on residential streets but warns that continuous community involvement is vital.

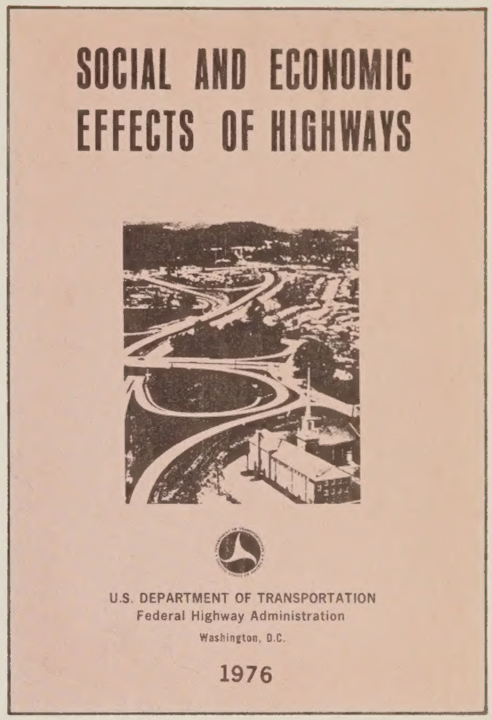
The report may be purchased for $5.20 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00111–0).



Effective Citizen Participation in Transportation Planning discusses methods of effectively involving the public in developing transportation plans. The citizen participation needs in each step of the transportation planning process are discussed and techniques that meet these needs are identified. Thirty-seven major techniques are discussed and are categorized by function: information dissemination, information collection, reactive planning, initiative planning, decisionmaking, or participation process support. Each technique is described in detail, its costs are discussed, and selected bibliographic references are provided. The report also includes eight case studies of actual participation programs.

Volume I of the report, **Community Involvement Processes**, is a discussion of the citizen participation processes and the case studies. Volume II is **A Catalog of Techniques**. A consistent reference system is provided so the reader can easily move between the two volumes.

Volume I may be purchased for $2.50 (Stock No. 050–001–00118–7) and Volume II may be purchased for $4.10 (Stock No. 050–001–00119–5). Both are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.



Social and Economic Effects of Highways highlights the effects of modern highways on individuals, communities, and regions. It contains a narrative portion synthesizing some of the experience gained in highway impact studies during the past 15 years. Abstracts of studies completed during the last 5 years, a brief description of studies underway, and an index by author and subject matter are also included.

This report is intended to help researchers, planners, and interested members of the public locate material on social and economic effects of highways. Its primary purpose is to suggest areas of needed research and to highlight past and present experience that may be relevant for estimating or influencing highway effects in the future.

The report may be purchased for $3.25 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00109–8).

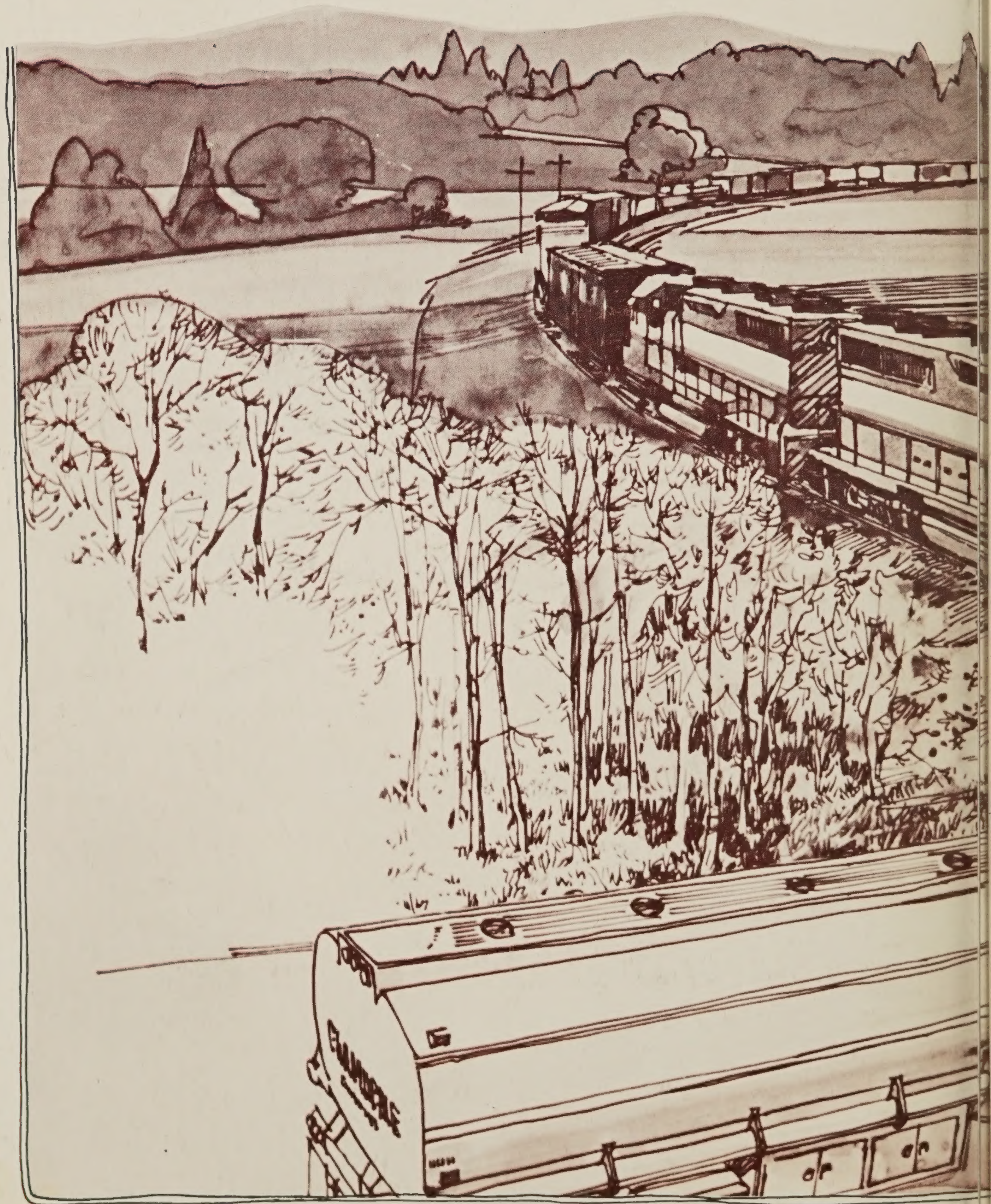
United States
Government Printing Office
Superintendent of Documents
WASHINGTON, D.C. 20402

Official Business

PENALTY FOR PRIVATE USE, $300
POSTAGE AND FEES PAID
FEDERAL HIGHWAY ADMINISTRATION
DOT 512

U.S.MAIL

FIRST CLASS



public roads

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT