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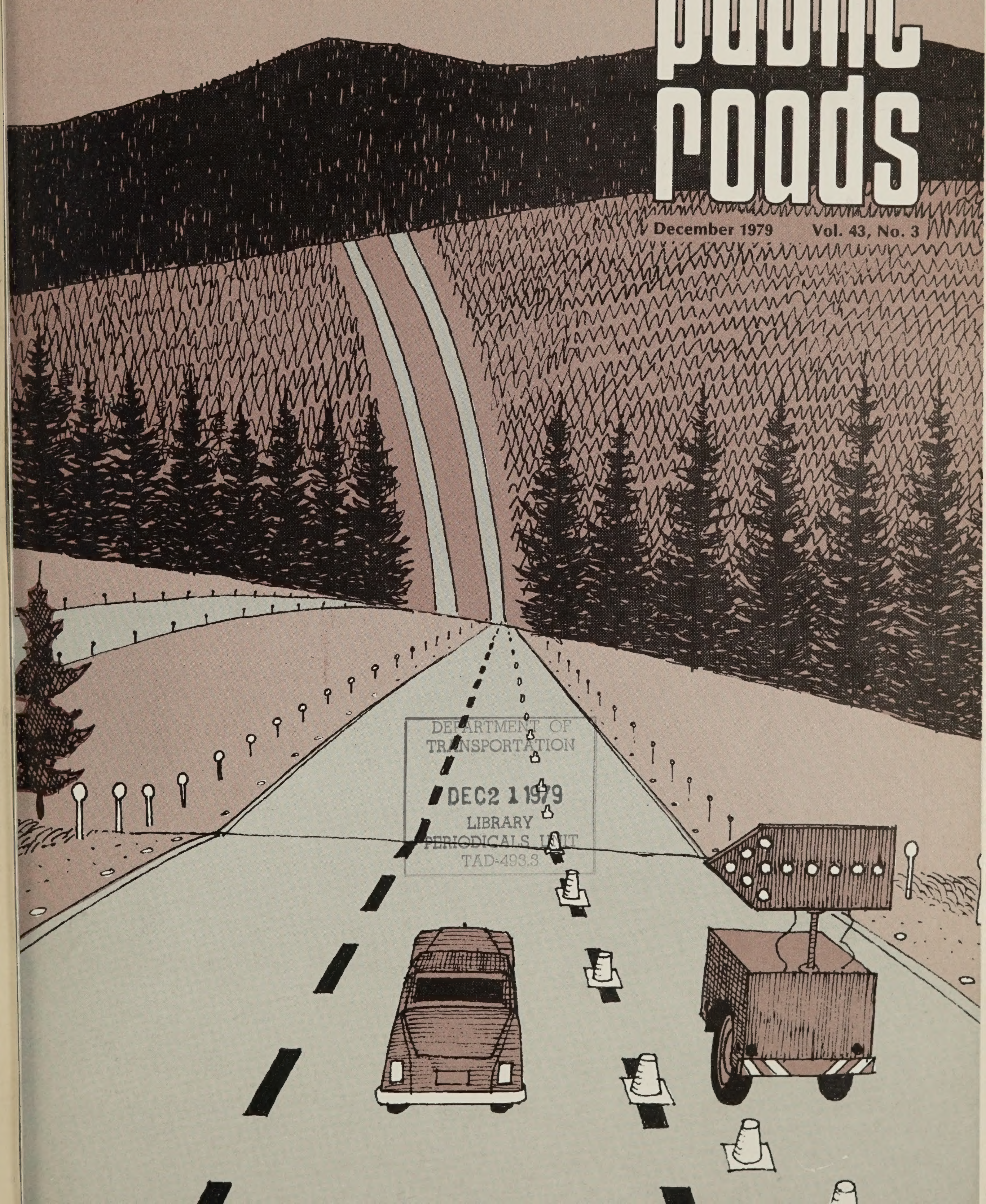

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COVER:
Artist's concept of lane delineation techniques.

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Is Delineation Needed?

by
Richard N. Schwab and Donald G. Capelle

The 1973 Federal-Aid Highway Act established a pavement marking demonstration program and a special research and development program to improve the effectiveness of highway delineation techniques. (*1*)[1] A major objective of the research program was to insure that delineation systems address motorists' needs for guidance and advisory information. This article discusses where, when, and how much delineation is required for safe and effective driving. Research that dealt with developing improved materials and technology for delineation was discussed in a previous article in *Public Roads.* (2)

What is Delineation?

Delineation is a device or treatment, excluding signs, that provides guidance and regulatory or warning information to a driver. (*3*) Delineation can be almost any feature of the roadway or its environment that shows the motorist the proper path to follow. These features can be devices specifically for delineation (painted centerlines or edgelines or postmounted retroreflectors installed on the shoulders) or construction details built into the roadway (joints in a portland cement concrete pavement, guardrails, rumble strips, or contrasting shoulder treatments [fig. 1]). Delineation also can be unintentional, such as an incidental part of the roadway environment—a fenceline, a row of trees, or the topography of the region (fig. 2). These surroundings, although visible in daylight, may not always provide sufficient nighttime guidance. Adequate guidance must be provided, especially at locations where natural or construction details may be misleading—for example, a pavement joint or a row of trees that continues straight ahead although the roadway curves.

Current U.S. roadway delineation practices are governed by the Manual on Uniform Traffic Control Devices (MUTCD). (*4*) The MUTCD provisions are general and permit various delineation treatments, materials, and patterns to compensate for different climatic and traffic conditions.

A series of research studies began in early 1975 to examine the effect of several types and patterns of delineation treatments on accident experience and traffic behavior. The goal of the research was to establish minimum and optimum delineation requirements based on driver behavior and to develop more specific recommendations for effective delineation.

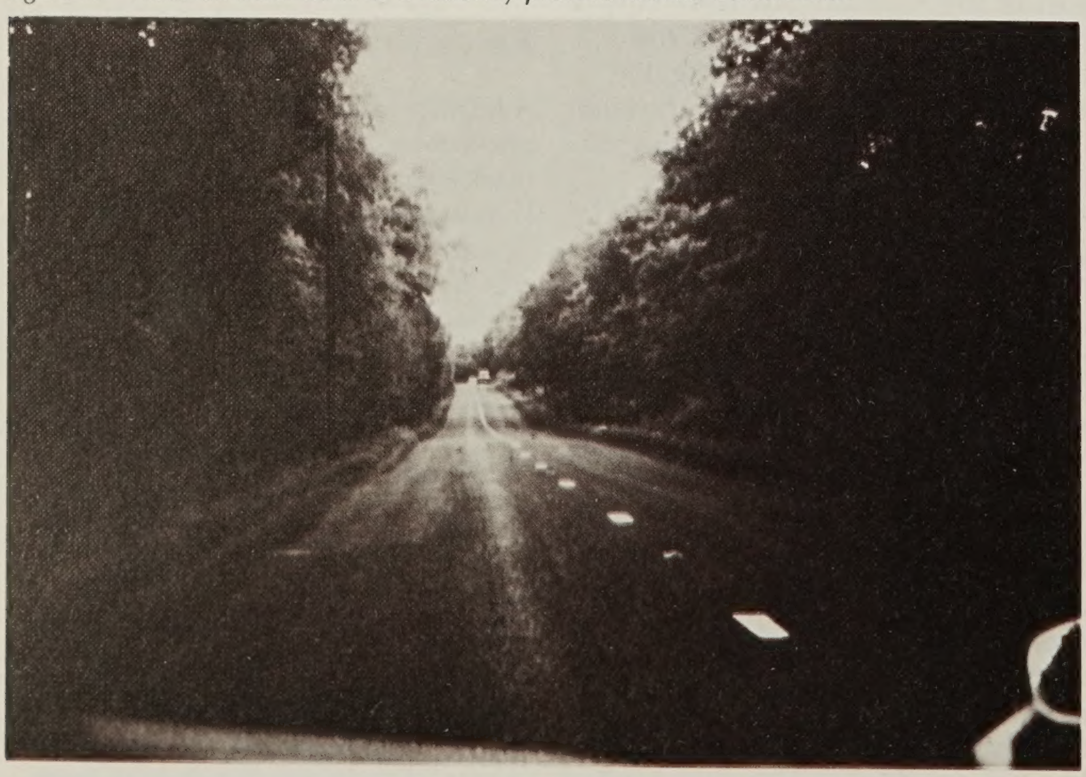
Research Approach

A human factors study investigated photometric standards for lane markings and developed more visible yellow paint markings. (*5, 6*) This research involved a driving simulator that used computer-generated outlines of a road and markings projected on a screen in front of a real vehicle passenger compartment. The consequences of decreased marking visibility were evaluated by the driver's ability to control the vehicle and by subjective ratings. Instrumented vehicle studies under real-world traffic conditions were used to validate the simulator findings. Color identification of yellow highway paint under typical daytime and nighttime illumination conditions was also studied in both laboratory and field tests.

[1] Italic numbers in parentheses identify references on page 96.

Figure 1.—Asphalt pavement with contrasting shoulder treatment.

Figure 2.—Trees on both sides of a roadway provide natural delineation.



A traffic performance study measured the effects of delineation on vehicular control and accident potential. (*7*) Traffic performance measures, such as the speed and lateral placement of vehicles within their lane of travel, were evaluated in relation to delineation changes, geometric changes, and environmental changes.

An accident analysis study investigated accident, geometric, climatic, and traffic data collected at approximately 500 sites in 10 States. (*8*) Over 13,000 accidents were analyzed at two types of highway sites: Matching-control sites and before-and-after sites. At the matching-control sites, accidents occurring at two geometrically similar sites (with similar traffic and climatic conditions) with different delineation treatments were compared. The delineation treatments *at each site* remained the same over the analysis period. At the before-and-after sites, accident data were available both before and after the installation of a specific delineation treatment. Cost-benefit analyses were performed at sites where significant differences in accident frequency could be attributed to delineation treatment.

Driver comprehension of road markings was investigated in a questionnaire study that assessed a driver's understanding of marking system principles and his or her ability to interpret actual road situations shown on film. (9)

Findings and Recommendations

The major findings of the research studies described above will be discussed in relation to their effects on the three major delineation treatments—stripes, raised pavement markers, and postmounted delineators. Application of each treatment is also discussed. The results of previous studies are included.

Stripes

The most common type of delineation is the paint stripe. One of the first issues addressed in the research program was the need for striping. Although the need for pavement marking, especially for a centerline, is rarely questioned, there are many kilometres of low-volume, two-lane roadways without any marking. Table 1 gives mean accident rates for two-lane roadways with average daily traffic (ADT) volumes of 500 to 5,000 vehicles. (*8*)

Striping reduced accidents approximately 30 percent; the data were significant at the 0.05 level. If this finding is extrapolated to traffic volumes lower than those observed in the study, centerlines can be cost beneficial at ADT volumes as low as 50 vehicles.

Driver behavior studies have shown that adding a centerline to a previously unmarked roadway reduced the road's predicted hazard level by almost 50 percent. (*10*) Therefore, there is strong evidence that the centerline should be used whenever a roadway has a paved surface that will retain a paint marking and is wide enough to carry two-way traffic.

Edgeline striping, shown in figure 3, is a generally accepted practice on major roadways, although its effectiveness has been questioned. The human factors study showed improved lateral stability with more conspicuous edgelines. (*5*) Similar results were obtained in the traffic performance study where performance improved with edgelines. (*7*) Results of the accident analysis study showed that edgelines improved safety somewhat; however, this improvement was greater on straight roads than on winding roads. (*8*) This is contrary to what might be expected. The authors suggest that this may illustrate the role of stress on driver attentiveness; that is, a driver is less attentive on straight roads and appears to rely on edgelines if it is necessary to respond to a particular driving situation. On winding roads where a driver is under stress and therefore already attentive to the driving task, he or

Figure 3.—Roadway with painted edgelines.

Table 1.—Accidents per million vehicle-kilometres for two-lane roadways with ADT volumes of 500 to 5,000 vehicles

Delineation treatment	Type of site: Tangent	Winding	All
No treatment	2.4[1]	2.0	2.1
Painted centerline only	1.4	1.6	1.4

[1] Ten or fewer sites with relatively large variance.

1 veh-km=0.62 veh-mile

she will not rely as much on the edgelines for guidance. A recent 2-year accident study in England has shown similar results. (*11*) There is also evidence of a major accident reduction at intersections having edgelines.

It can be concluded that edgelines are important in a roadway delineation system and should be used on major roads wider than 6 m (20 ft). If traffic safety is the only consideration, an ADT volume of 1,000 vehicles is necessary to make edgelines cost beneficial. If other factors are considered, such as reduced costs for shoulder maintenance, edgelines may be justified on roads having ADT volumes lower than 1,000 vehicles.

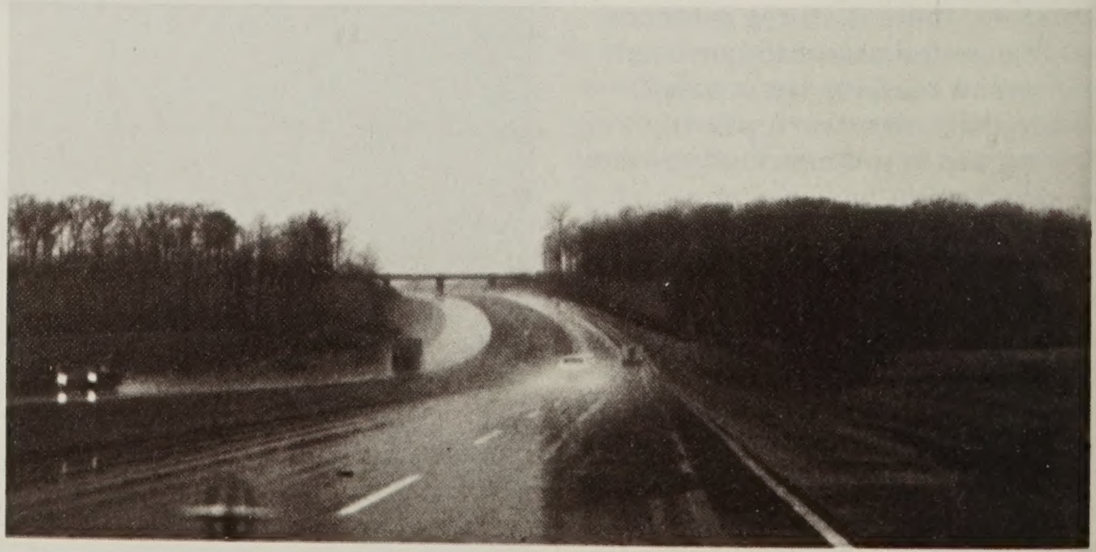
Delineation is coded to convey certain information to drivers. Rules for coding, provided in the MUTCD, include the elements of color, shape, size, and configuration. (*4*) Use of a two-color system for pavement markings has been questioned in recent years. Yellow paint is slightly more expensive than white paint and is less visible under adverse weather conditions. The toxicity of the lead chromate pigment used in yellow paint is another concern. According to the MUTCD, a yellow pavement marking means that "traffic on the other side of a yellow marking" is moving in the opposite direction. (*4*) The questionnaire study demonstrated that many drivers do not understand this. (*9*) Most drivers associate yellow with warning signs and caution signals, that is, a hazard. Therefore, a more aggressive driver education program is needed for this code to be effective.

The human factors study also showed that the yellow paint presently used can be desaturated considerably in rural areas where there is little or no fixed roadway lighting. (*6*) A mixture of 50 percent white pigment to 50 percent yellow pigment, by weight, will not decrease color identification for most drivers. In urban areas having considerable fixed lighting, however, the dilution should be much less (not more than 30 percent white pigment, by weight, should be used), particularly as the use of sodium vapor light sources increases. Limited field evaluation of "lightened" yellow is underway in several areas of the United States and more research is planned. If the dilution of yellow pigment is operationally acceptable, the annual savings can be significant.

The MUTCD requires a stripe-to-gap ratio of 1:3 for both centerlines and lanelines. (*4*) Usually, stripes are 3.05 m (10 ft) long and gaps are 9.14 m (30 ft) long. The traffic performance study found little difference in driver performance for various stripe-to-gap ratios in dry weather when sight distance was good. (*7*) In wet weather the results were similar, although data were limited and the amount of rain was not quantified. The human factors study showed that in heavy rain the stripe-to-gap ratio has a significant effect on steering performance, especially when forward visibility is restricted. (*5*)

In summary, although the 1:3 stripe-to-gap ratio is adequate for most roadways, it may need to be supplemented in situations where forward visibility may be restricted (fig. 4). (*12*) In mountainous terrain or where climatic conditions commonly cause restricted visibility, the 1:3 stripe-to-gap ratio should be supplemented by raised pavement markers. Such markers show up particularly well at night in fog and rain when paint markings are not as effective.

Figure 4.—Loss of effectiveness of paint markings because of rain.



Raised pavement markers

Raised pavement marker use has greatly increased in the past 10 years, and markers now play an important role in many delineation treatments. A raised pavement marker is shown in figure 5. The major advantages of these markers over paint stripes are reduced maintenance and more positive all-weather, nighttime delineation. The major disadvantages are high initial cost and possible incompatibility with snowplows. Snowplowable raised pavement markers have become available in recent years but are more expensive. Early research with snowplowable markers indicated that they could not be used with tungsten carbide snowplow blade inserts. However, recent field experience with 1.5 million markers in Ohio indicated that this restriction may no longer be true.

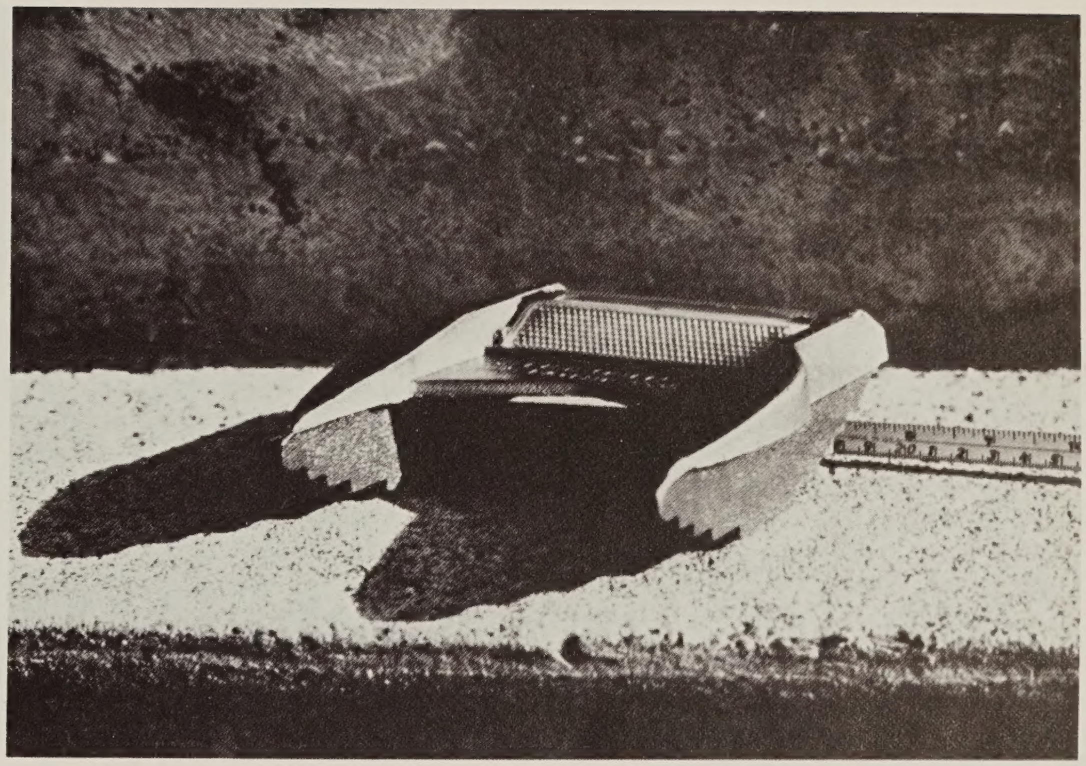
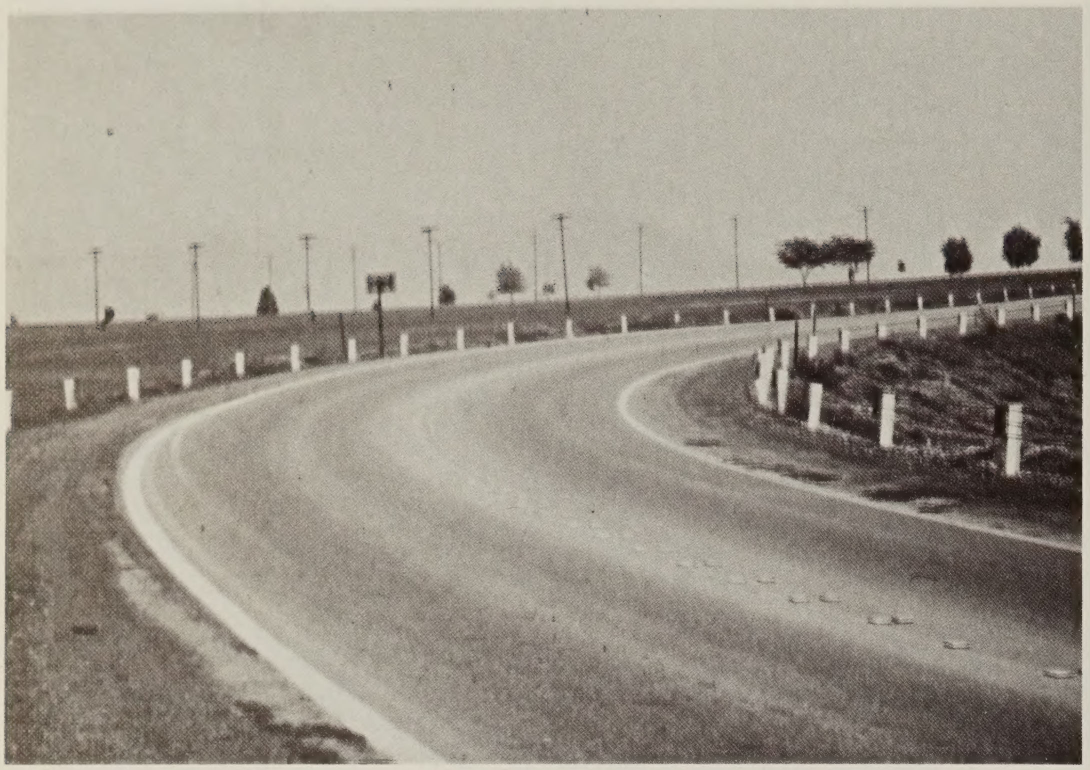


Figure 5.—A raised pavement marker before installation.

Raised pavement markers have widely replaced painted centerlines, especially in the sunbelt States (fig. 6). Typically, four nonreflective raised markers are used in place of the stripe, and a retroreflective marker is placed at the center of every other gap. This type of marking reduces the amount of lane changing and discourages encroachments onto opposing lanes, possibly because of the rumble effect produced when running over the markers. Research has shown that raised pavement markers reduce a vehicle's lateral placement variance and driver stress at night in wet weather. (*5, 7*) Accident analysis studies showed that when painted centerlines were replaced with raised pavement markers, there was reduction of approximately 0.31 accidents per million vehicle-kilometres (0.50 accidents per million vehicle-miles). (*8*) In areas with no snow and where markers have a service life of 5 years and cost less than $2,500 per kilometre ($4,000 per mile) to install, raised pavement markers are cost beneficial at an ADT volume of 3,000 vehicles.

Because of the high initial cost of raised pavement markers, especially the snowplowable types, many highway agencies have supplemented standard painted centerlines with retroreflective raised pavement markers every 24.4 m (80 ft) to develop an all-weather delineation system at minimum cost. The cost of such a supplemental system, $620 to $930 per lane kilometre ($1,000 to $1,500 per lane mile), is considerably lower than the cost of complete replacement. In the human factors and traffic performance studies, hazards were reduced 30 to 40 percent with this type of treatment. (*5, 7*)

The traffic performance study indicated that raised pavement markers are more effective than postmounted delineators on isolated horizontal curves. (*7*) Raised pavement markers provide steering guidance in the area near the driver where actual steering decisions are made and provide far-distance information needed by drivers to anticipate road alinement changes. Raised markers also provide for a more accurate perception of the driving situation than do most other forms of supplemental delineation. Research suggests that one-way raised pavement markers along the outside of each driving path are more effective than two-way centerline markers for minimizing off-center driving on a two-way curved roadway. The cost effectiveness of such an installation depends on the particular site.



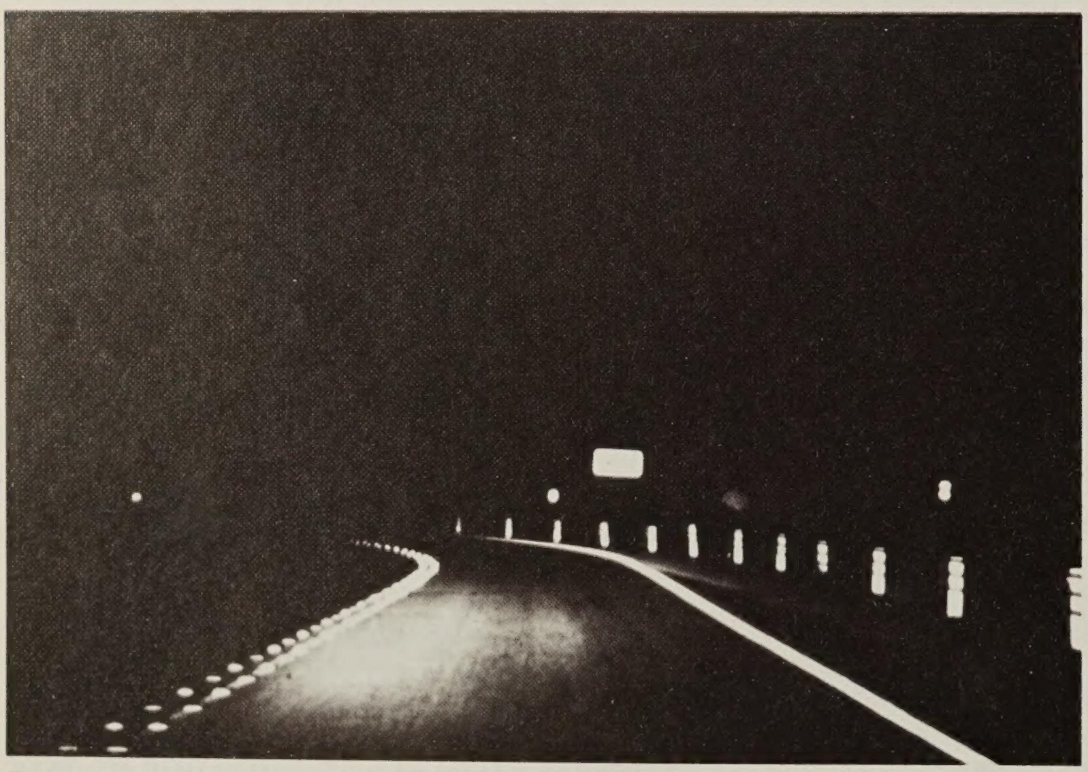


Figure 6.—Daytime view (above) and nighttime view (below) of raised pavement markers used for centerline delineation.

Postmounted delineators

Postmounted delineators of various shapes, colors, and reflective characteristics are used widely throughout the United States. These markings have proven especially effective at night and in adverse weather when standard paint markings are covered by snow or water. They provide the driver with a preview of roadway direction, but they are not very useful for near-roadway steering information because of their offset location.

Accident rates are significantly lower were postmounted delineators are used; a reduction of approximately 0.6 accidents per million vehicle-kilometres (1 accident per million vehicle-miles) has been demonstrated. (*8*) The postmounted delineator, therefore, can be very cost effective as an edge marking. If safety is the only benefit considered, such treatment is cost beneficial at all reasonable values of installation cost and service life for ADT volumes exceeding 1,000 vehicles. In many cases, depending on local service and cost specifics, such treatments can be justified for ADT volumes as low as 500 vehicles.

As with raised pavement markers, the selective use of postmounted delineators as a supplement to standard pavement striping appears to be cost effective for all weather conditions (fig. 7). In the traffic performance study, performance improved significantly with the use of postmounted delineators on horizontal curves. (*7*) The accident analysis study demonstrated a lower accident rate at isolated horizontal curves where postmounted delineators supplemented the standard paint markings than at matching-control sites without postmounted delineators. (*8*) However, the sample size was too small to make a definitive conclusion.

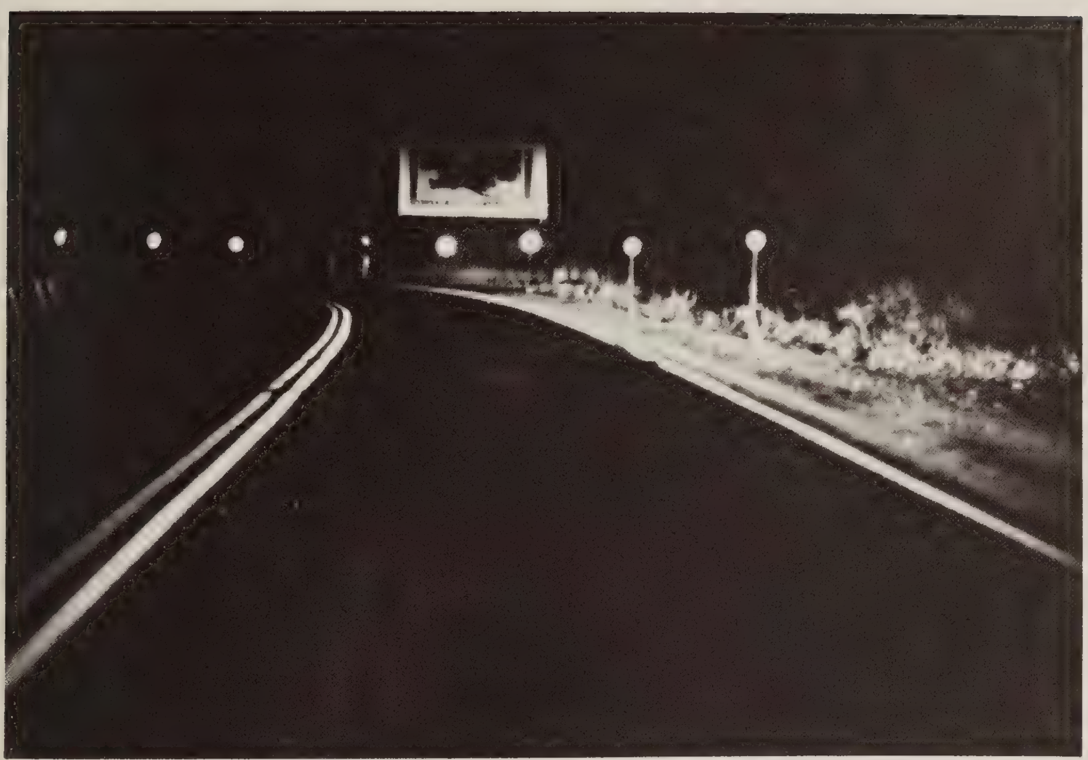


Figure 7.—Painted edgelines supplemented with postmounted delineators.

Discussion of Findings

Based on the findings of this research program, it was concluded that centerline delineation is highly cost beneficial and should be used on any paved roadway that carries two or more lanes of through traffic. If a low-volume roadway warrants the expenditure for paving and maintaining that surface, it certainly warrants the additional annual expenditure of $30 a kilometre ($50 a mile) to maintain a centerline and reduce accidents 30 percent. Delineation of the outside edge of the travel lane is also highly desirable, especially for roads wider than 6 m (20 ft). Postmounted delineators are somewhat more effective for this application than edgelines, but both treatments are especially useful for roadways with high ADT volumes.

There is substantial evidence that delineation provides important guidance information to motorists, especially when visibility decreases due to adverse weather or nighttime conditions, and that there is little difference in effectiveness between various delineation materials and treatments as long as there is adequate contrast and enough continuity to the delineation to inform the driver of roadway direction. For this reason, least life-cost systems are usually preferred for most roadway situations.

The above conclusions do not rule out the need for delineation in excess of minimum standards at certain locations. For example, standard delineation systems supplemented by other delineation treatments to improve traffic flow for nonstandard, high-hazard situations are generally very effective and result in great safety benefits. Among the critical locations that should be considered for such supplemental treatments are isolated horizontal curves, areas where driver expectation is different from what is actually encountered, and areas frequently subject to reduced visibility from dense fog, blowing snow, or heavy rain.

The state of the art is well enough established to provide minimum standard delineation treatments for general situations in terms of color, configuration, and contrast. General guidance is available to determine when these standard treatments should be supplemented. Better definition and solutions for determining where, when, and how much delineation should be provided are still needed. However, much of the remaining effort depends on local problemsolving for unique applications. This research program has developed the tools needed to evaluate alternative solutions.

In general, it can be concluded that wider application of conventional delineation treatments is desirable and will significantly reduce accidents.

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[2] Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

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Development and Testing of Advanced Control Strategies in the Urban Traffic Control System

by

John MacGowan and Iris J. Fullerton

This is the second in a series of articles that traces the evolution and accomplishments of the Urban Traffic Control System (UTCS) research project. This series highlights the research activities undertaken in the past 10 years and stresses the potential application and anticipated benefits accruing from this major research project. The first article, published in *Public Roads,* vol. 43, No. 2, September 1979, described the development of offline signal timing programs, the provisions of the real-world fully instrumented laboratory established in Washington, D.C., and the first generation control strategy. This second article summarizes the hardware and strategies of the Bus Priority System (BPS), describes the second and third generation software systems, evaluates the various strategies, and presents research in traffic simulation and vehicle detection. The next article will present the technical accomplishments of the UTCS research project.

Bus Priority System

The Bus Priority System (BPS) study extended the original scope of the Urban Traffic Control System (UTCS) project. (*1*)[1] Operational hardware and computer software were developed to reduce bus delays in an urban network by providing preferential treatment to buses at signalized intersections. The test network consisted of 144 installations at 72 approaches of 34 intersections.

BPS hardware

The BPS configuration is shown on the flow diagram in figure 1. The system uses near-field radio frequency transmissions, a buried single-turn loop antenna, and a standard radio receiver circuit design.

The design configuration consists of an antenna buried in a single saw-cut across all lanes of an approach. A typical installation of bus antennas in relation to vehicle detector loops is shown in figure 2.

The bus detector transmitting equipment consists of the operator control lever and the radio transmitter located underneath the bus. The control lever hardware mounted on the steering wheel column is a modified turn indicator switch. The switch's position dictates which one of two frequencies (stop or through) is transmitted by the bus-mounted transmitter.

The bus detector receiver is a simple design consisting of two independent parallel channels containing an amplifier, a detector, and output circuits. (*2*) It is packaged into a plug-in module the same size and shape as the UTCS communication transmitters and receivers and operates from the same power supplies.

[1] Italic numbers in parentheses identify references on page 104.

The bus detector receiver output signals connect to a three-frequency-shift-keyed (FSK) communications transmitter that sends the appropriate signal over leased telephone lines to a bus detector communications receiver located at the computer center.

A BPS-dedicated computer in the control center was used for BPS operation and shared the UTCS computer memory. The BPS supplied the correct traffic signal interval timing and relied on the UTCS for signal advance pulses, as well as for all other control functions.

The field hardware operated reliably during a test period of 81 weeks; an onboard transmitter, switch, or power supply had a mean time between failure (MTBF) rate of approximately 47,700 hours.

BPS strategies

The original objective of the BPS algorithm was to increase passenger throughput and decrease passenger delay without disrupting other traffic. (*3*)

The method of granting priority to buses at intersections is shown in a simplified flow diagram (fig. 3). If there is a minimum net intersection gain[2] of 2 minutes by extending the green time and allowing the bus to pass through the intersection, then the green time would be extended for up to 10 seconds.

Because this algorithm was very conservative, the delay was reduced for relatively few buses. Also, assumptions had to be made to satisfy algorithm requirements for data that were not directly observable from the surveillance system. This reduced the effectiveness of the BPS. (*3*) It was also assumed that bus operators placed the "stop/through" switch in the correct position.

Recognizing these shortcomings, a second algorithm was developed for providing preferential treatment to buses at an intersection.

The new algorithm was a preemptive strategy using the same bus detector configuration. In addition to the green time extension, red time could be truncated. A bus arriving at the upstream detector during the red phase was immediately granted an early green signal, provided the cross street minimum green time had been achieved. A simplified flow chart of this priority method is shown in figure 4. No provision was made to correct extended or truncated offsets.

[2]Intersection gain is bus passenger gain (bus passenger benefits) plus car passenger gain (experienced by cars in the same phase with the bus) minus the cross street car passenger loss due to lost green time.

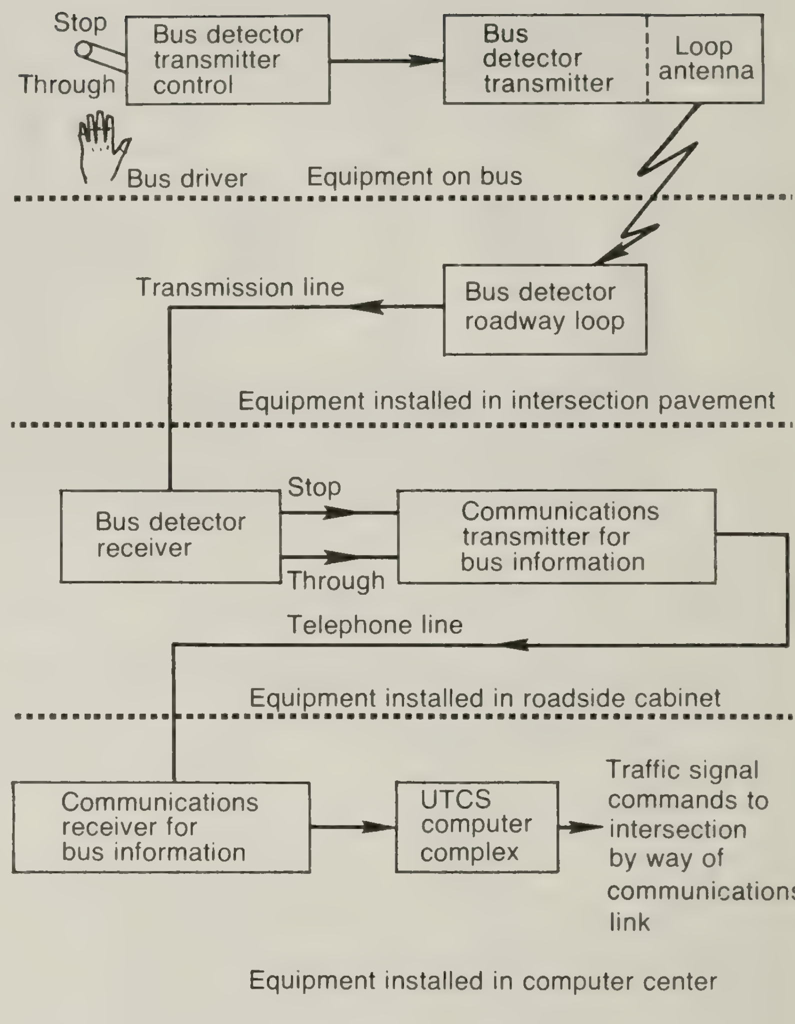
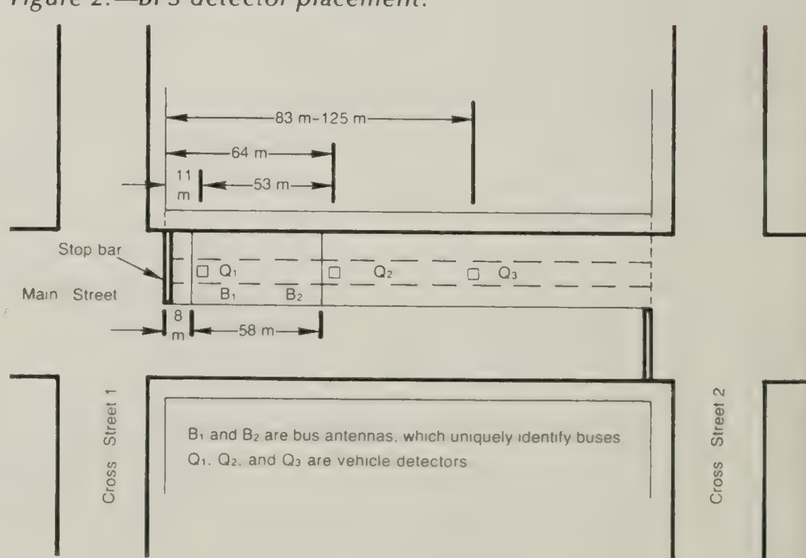


Figure 1.—BPS signal flow block diagram.

Figure 2.—BPS detector placement.



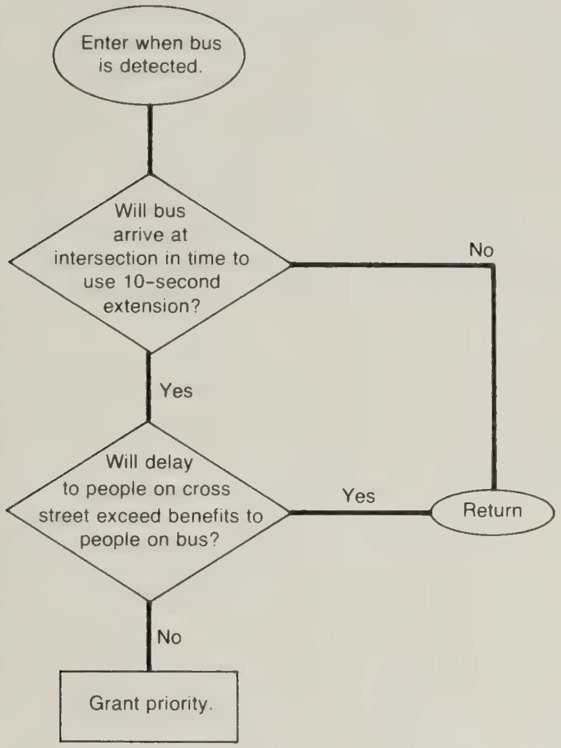
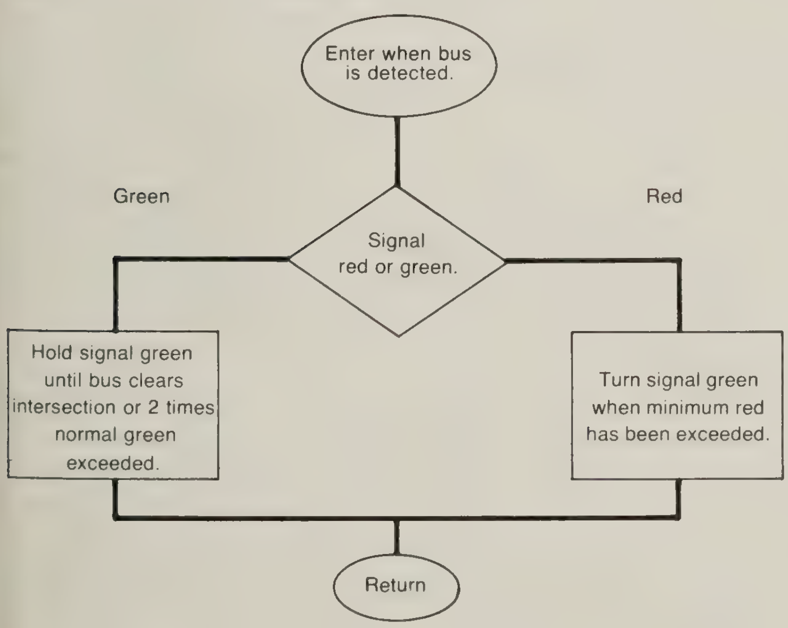


Figure 3.—First BPS algorithm flow chart.

Figure 4.—Second BPS algorithm flow chart.



Two significant modifications were made during field testing. The first allowed the offset to be corrected to the desired offset over a number of signal cycles when an intersection became inhibited from BPS operation.

The second modification introduced a vehicle saturation threshold to inhibit an intersection for bus operation. The saturation threshold was based on the measured flow (a function of vehicle volume and occupancy). If an approach to the intersection carried flow exceeding the threshold, then BPS would become inhibited at that intersection.

Simulation and evaluation

A series of simulation tests using the NETSIM model, which is discussed later in this article, preceded field testing and evaluation of the revised algorithm. During this phase, the new algorithm was incorporated into the model and experiments ascertained the impact of the new strategy on buses and other vehicles. The simulation tests showed that when buses preempted other traffic at signals there was approximately a 20 percent decrease in net bus delay; however, speed of other traffic was decreased by approximately 10 percent.

Numerical results from an onstreet evaluation, including the impact on the overall vehicle population, are presented in table 1. (*4*) The results show relatively small degradation to the total system. Tables 2 and 3 indicate that a preemptive strategy will decrease bus travel time. The magnitude of both positive and negative values in these tables indicates the results are inconsistent. During peak periods, buses traveling opposite peak direction were as likely to trigger a preemption as fully loaded buses traveling in the peak direction.

The northbound approach of the 18th Street and Pennsylvania Avenue intersection in Washington, D.C., shows significant bus delay during the morning peak (table 2). This was caused by continuous high pedestrian movement across Pennsylvania Avenue during 18th Street green time extensions, which blocked a major right turn bus movement. The relationship between pedestrians and the preferential treatment of buses must be considered in future applications.

Bus travel time was reduced nearly 3 percent on the shorter route (Route No. 1 in table 3) where the ratio of instrumented approaches to noninstrumented approaches was higher than on longer routes (Route No. 2 in table 3). Frequent noninstrumented approaches on Route No. 2 probably caused the overshadowing of positive systemwide results.

Bus travel time may be reduced at midday with minor impact on other vehicles, probably because of the less critical nature of signal offsets at that time.

Second Generation Control System

The second generation control (2-GC) strategy is a real-time, online system that computes and implements signal timing plans based on surveillance data and predicted changes. (5) The 2-GC program, designated TANSTP (Traffic Adaptive Network Signal Timing Program), retained many features of the first generation control (1-GC) UTCS software and hardware, such as the basic executive logic, surveillance system, controller timekeeping, man/machine interface, selection of prestored timing plans through the manual or time-of-day modes, and hardware failure detection. The optimization process is repeated at 5-minute intervals. Although new timing plans were available, they could not be implemented more often than every 10 minutes to avoid developing control parameters based on conditions that exist during signal timing transition.

Table 1.—BPS impact on total vehicle movements

Time	Vehicle minutes of travel			Vehicle minutes of delay			Derived average speed (veh-miles per veh-mins)		
	BPS	Base	Net	BPS	Base	Net	BPS	Base	Net
A.M.	13,087	12,774	−313[1]	8,324	8,115	−209	6.86	7.16	−.30
Midday	12,487	12,414	−73	8,215	8,160	−55	6.39	6.52	−.13
P.M.	12,232	12,238	+6	7,844	7,818	−26	6.68	6.78	−.10

[1] Negative values indicate a degradation in the system as compared to the base system; positive values indicate an improvement.

1 veh-mile = 1.6 veh-km

Table 2.—Intersections' performance as measured by bus travel time from the upstream detector through the intersection

Approach	Time	18th & Pennsylvania (Mean time) with XMTR[1]	without XMTR	Difference	14th & K (Mean time) with XMTR	without XMTR	Difference	Wisconsin & Macomb (Mean time) with XMTR	without XMTR	Difference
		Minutes	*Minutes*	*Percent*	*Minutes*	*Minutes*	*Percent*	*Minutes*	*Minutes*	*Percent*
Northbound	A.M.	1.09	.92	−19.1[2]	.82	.95	+14.9	.34	.31	− 7.3
	Midday	1.09	1.34	+18.5	.96	.92	− 5.1	.44	.47	+ 4.9
	P.M.	1.35	1.44	+ 5.8	.98	1.13	+13.6	.37	.39	+ 6.2
Eastbound	A.M.	.84	.96	+12.8	.66	.72	+ 8.5	—	—	—
	Midday	.69	.76	+ 9.6	.66	.76	+12.5	—	—	—
	P.M.	.82	.82	0.0	.78	.80	+ 1.9	—	—	—
Southbound	A.M.	—	—	—	1.24	1.37	+ 9.2	.34	.41	+15.3
	Midday	—	—	—	1.05	1.30	+19.5	.53	.42	−27.6
	P.M.	—	—	—	1.25	1.37	+ 8.4	.35	.43	+18.8
Westbound	A.M.	.75	.70	− 6.5	.56	.63	+11.8	—	—	—
	Midday	.48	.83	+42.1	.53	.64	+17.6	—	—	—
	P.M.	.79	.73	− 8.1	.62	.74	+17.1	—	—	—
Average (all approaches)				+ 5.9			+10.2			+ 2.6

[1] XMTR = BPS transmitter.
[2] Negative values indicate degradation of BPS-equipped buses; positive values indicate improved travel time for BPS-equipped buses.

Table 3.—Route performance as measured by bus travel time along the route

Approach	Time	Route No. 1 Distance	1 (Mean time) with XMTR[1]	1 (Mean time) without XMTR	1 Difference	Route No. 2 Distance	2 (Mean time) with XMTR	2 (Mean time) without XMTR	2 Difference
		km	*Minutes*	*Minutes*	*Percent*	*km*	*Minutes*	*Minutes*	*Percent*
Eastbound	A.M.	1.5	7.92	8.46	+6.38[2]	5.6	24.11	23.56	−2.33
	Midday		8.88	8.59	−3.37		23.70	23.08	−2.66
	P.M.		10.00	10.24	+2.34		25.50	25.64	+0.54
Westbound	A.M.	1.3	6.45	6.79	+5.00	5.6	22.78	22.12	−2.98
	Midday		7.33	7.44	+1.47		23.93	23.99	+0.25
	P.M.		9.96	9.11	+1.64		27.34	26.50	−3.16
Average (all approaches)					+2.91				−1.73

[1] XMTR=BPS transmitter.

[2] Positive values indicate improved travel time for BPS-equipped buses; negative values indicate degradation of BPS-equipped buses.

1 km=0.62 mile

Operational features

The 2-GC software provides the following features:

- Optimization algorithm—The OPTIMIZ module of the SIGOP program was selected because of its short execution time, moderate computer memory storage requirement, and its simple and explicit mathematical optimization function (a quadratic equation of stops and delay terms).
- Traffic prediction model—Selected to predict the volume and speed as a function of historical volume and speed so that computed timing plans do not slow down current flow conditions.
- Subnetwork configuration models—The 2-GC software can improve optimization efficiency by dynamically reducing the total network into subnetworks on the basis of prevailing traffic conditions.
- Critical intersection control (CIC)—The CIC routine for 2-GC involves changing the cycle splits and offsets for certain intersections once per cycle as a function of the demand (computed values of queues and volume on these links).
- Transition model—The transition from a current timing plan to a newly computed timing plan is optimized by determining the value of a parameter, which when added to the new offset at each intersection will minimize the transition time.

Third Generation Control System

The third generation control (3-GC) UTCS software was developed to implement and evaluate a fully responsive, online traffic control system. (6) The 3-GC software was designed to permit the cycle length of each controller to vary from cycle to cycle. This design approach differentiates 3-GC from those control systems that provide a sequence of fixed-time, cycle-based signal timings. The 3-GC software system interfaces with existing field controller hardware; therefore, the local dial system remains intact and provides a backup (standby mode) for the computer-based system. Both 1-GC time-of-day and manual modes can be used.

Operational features

The unique operational features of 3-GC software provide for the following:

- Signal timing is computed for all controllers at least once every 3½ minutes.
- Signal offset and split are determined to minimize vehicle delay and stops along each approach and provide networkwide coordination.
- Congestion paths are identified and the control algorithm is specifically designed to service a congested condition while the condition persists.

• Transition routines are not needed because the system is constantly in a state of transition as it responds to changing traffic conditions.

Optimization algorithm

In the 3-GC traffic responsive mode, signal timing plans are developed by either of two optimization algorithms: The Cycle-Free Responsive Algorithm for Network Optimization (CYRANO) provides signal timing for undersaturated conditions, and the Congested Intersection Control coupled with Queue Management Control (CIC/QMC) provides areawide signal timing for saturated conditions on congestion paths.

Signal coordination is accomplished in CYRANO by implementing a coarse simulation of traffic flow and then systematically adjusting the signal settings at each controller to minimize disutility (a linear combination of vehicle stops and delay aggregated over all approaches). The objectives for the CIC/QMC are to maximize throughput at the congested critical intersections to provide acceptable service for the two congested competing demands and to manage the queue formation along the paths leading to the critical intersection so that the intersection is blocked and green time is fully utilized.

Evaluation of UTCS Software

The evaluation of UTCS included an intensive two-phase study to determine the effectiveness of the three generations of control systems and an evaluation of the 1-GC system recently installed in New Orleans, La.

Phase I evaluation

The phase I evaluation, conducted from March 1974 to November 1974, compared the 1-GC strategies and the existing Washington, D.C., three-dial, pretimed traffic control system. (*4*) All the traffic control plans were programed for the computer and were implemented with the computer as the master controller. This UTCS/BPS evaluation network included 114 signal-controlled intersections in central Washington, D.C., and along two primary arterials.

In the phase I evaluation, data were collected from the electronic surveillance system and from four survey vehicles traveling through the control area. To evaluate the BPS control alternatives, special studies were conducted to measure bus activity.

The results of the phase I evaluation will be fully discussed in the next article in this series. The major conclusions are summarized below.

• Generally the traffic responsive (TRSP) control alternative compared favorably with all other control alternatives.

• The CIC operations distributed delay equally on the approaches to a given intersection, but had little effect on overall system operations.

• The BPS algorithm worked well when the offset from the previous intersections was not critical. Overall traffic delays were increased by only 0.3 to 2.5 percent, so the effect on motorists was minimal. Bus delays were reduced as much as 42 percent at one intersection; however, most delay savings were lost because not all intersections along the bus route were equipped to operate with BPS control.

• The measures of effectiveness calculated from the surveillance system compared well with those obtained from the moving car surveys.

Phase II evaluation

Phase II of the evaluation study, conducted from February 1976 to May 1976, evaluated 2-GC and 3-GC (CYRANO only) strategies. (*7*) The TRSP and the Washington, D.C., three-dial control alternatives of phase I were reevaluated.

The evaluation methodology used for phase I was changed for phase II because the higher order measures of effectiveness, including delay, would not be generated when the 2-GC and 3-GC were online. The phase II evaluation was based on travel time measurements made by moving survey vehicles and by relying on the surveillance system for volume measurements only.

Phase II evaluation results will be fully discussed in the next article of this series. The major conclusions are summarized below.

• The 2-GC strategy was comparable to the Washington, D.C., three-dial alternative, except for the evening peak period in one area of the network where there was a relative degradation in performance.

• The 3-GC strategy was the least effective of the new concepts tested, indicating that more research is needed before it can be thoroughly tested.

• Although the TRSP alternative did not compare as favorably to the Washington, D.C., three-dial alternative as it did in phase I, the changes in the traffic patterns because of the completion of the subway construction may account for the TRSP decline in effectiveness.

New Orleans evaluation

The city of New Orleans, La., installed a new computer-based signal system that uses the concepts developed for the UTCS in Washington, D.C. The New Orleans system is one of the first to use the FORTRAN IV version of 1-GC UTCS.

Basically, the evaluation focused on onstreet measures of performance and system operation measures of performance. (*8*)

Benefits of a computer-based system include the following:

- A map display identifies abnormal traffic conditions and a control console revises signal settings in real time.
- Summary performance reports identify long term changes in traffic demand and indicate when to generate new signal plans or modify existing ones.
- New street timing plans can be debugged (tested onstreet) efficiently by defining a new plan in the data base.
- Hardware monitoring immediately identifies detector or controller failure, permitting rapid response to equipment malfunctions. Hardware monitoring will also reduce false maintenance calls, allowing more efficient scheduling of maintenance crews.

General conclusions drawn from the evaluation include the following:

- There were improvements over the existing plans of 8.8 percent for time-of-day and 8.5 percent for TRSP.
- The initial cost of a computer-based system in New Orleans was approximately 80 percent greater than the cost of a conventional system.
- Only minor differences in operations and maintenance costs were found, except that a computer-based system requires a full-time operator and a computer maintenance contract.

Research in Traffic Simulation

Shortly after the UTCS project was initiated, it became evident that an analytical model was needed to test and evaluate alternative network strategies in a "laboratory" prior to committing time and resources to installing the new control strategies in the Washington, D.C., network. The Federal Highway Administration (FHWA) sponsored the development of such a model. (*9*) It was originally designated UTCS-1 because of its relation to the UTCS project but was renamed NETSIM.

Model development and validation

The NETSIM model describes a street network in a series of interconnected links and nodes. Each link carries traffic in one direction and the nodes are link intersections. Traffic is processed in a series of short time-steps subject to varying forms of traffic control. Vehicle movements are very detailed in NETSIM, and the model can treat most of the major forms of traffic control found in U.S. cities. It is written in FORTRAN IV language for operation in virtually any large computer.

The model was first validated by tests in 1971 and 1973 when key outputs were compared with equivalent field data collected by aerial photography. In 1976, capabilities to estimate vehicle fuel consumption and vehicle emissions were added to the model. New logic for traffic-actuated signals was introduced into the model in 1977.

NETSIM applications

Some of the applications of NETSIM during the UTCS project are listed below.

- Tested the transition techniques between different signal settings.
- Compared traffic signal optimization models.
- Analyzed CIC schemes.
- Analyzed potentials of alternative methods of giving preferential treatment to buses at signalized urban intersections.

Research in Vehicle Detection

Several research studies in the UTCS project addressed detector technology. Installation techniques were increased, detector location for computer-based control systems was determined, and innovative detectors, such as the magnetic vehicle detector and self-powered vehicle detector, were developed.

Loop detector tests

The inductive loop detector used in the UTCS project consisted of a few turns of wire embedded in the roadway pavement. The wires were connected to an electronic component located in a cabinet at the side of the road. The detector was designed so that a vehicle passing over the loop in the pavement modified the magnetic flux around the resonantly tuned loops of wire. This increased or decreased the inductance so that a change in resonant frequency, impedance, amplitude, or phase was detected by the transistorized roadside unit and transmitted to an amplifying or relay circuit.

An extensive loop detector testing program was part of the UTCS facility specification effort to determine the accuracy, reliability, and maintainability of fixed-frequency inductive loop detectors. (*10*)

Installation techniques

Because vehicle detectors are key elements in surveillance subsystems, their performance and system cost can have a major impact on traffic control systems. FHWA developed an improved vehicle detector with low installation cost. (*11*)

Detector location study

A special study was conducted to determine the most effective location and placement of detectors for the advanced UTCS traffic control strategies. (*12*) The following conclusions were made:

- 1-GC and 2-GC CIC algorithms require detectors on all major approaches to a CIC-controlled intersection.
- 1-GC requires detectors on approximately every fourth link of an arterial and every third link of a network grid.
- 2-GC requires detectors on every other link on streets with uniform flows and more frequently on streets with fluctuating flows.
- A detector located in one "critical" lane can usually identify demand on a multilane approach.
- Detectors should be placed approximately midblock or 61 m (200 ft) upstream of the stopline.

Magnetic gradient vehicle detector (MGVD)

The MGVD consists of a transducer measuring 2 083 by 38.1 by 12.7 mm (82 by 1.5 by 0.5 in), cables, and roadside detector electronics. (*13*) The transducer is installed in a slot in the pavement, at right angles to the direction of vehicle travel.

In a 1974 test conducted by FHWA personnel, the performance of the MGVD was compared with inductive loop detectors and no significant difference was found. FHWA later developed a phase mode vehicle detector (PMVD), instead of the amplitude mode, but still using the MGVD transducer. The PMVD requires less than one-tenth of the power and is less costly to build than the amplitude mode. In 1976, four PMVD's were installed in the UTCS network using the MGVD transducers. An evaluation of the performance of this set of electronics resulted in a design change to the transducer.

The improved models of the MGVD/PMVD are being evaluated under the Federally Coordinated Program of Highway Research and Development, Project 2L "Detection and Communication for Traffic Systems."

Self-powered vehicle detector (SPVD)

An SPVD was developed to significantly reduce the time, cost, and traffic disruption associated with detector installation by eliminating the need to cut slots in the pavement for connecting cables between the detector and the roadside. (*14*)

The SPVD roadway unit consists of an internal power source, transducer, and radio transmitter with loop antenna. It is packaged in a cylinder and is readily removable for servicing. The power source is a lantern battery with a minimum life expectancy of 1 year. The transmitter with loop antenna has an effective range of 152 m (500 ft) from the detector to the roadside equipment.

An evaluation of the SPVD prototypes revealed major design problems with the magnetometers (a portion of the transducer) and telemetry link. Improved production prototype models of the SPVD were developed and are currently being evaluated in the field under Project 2L.

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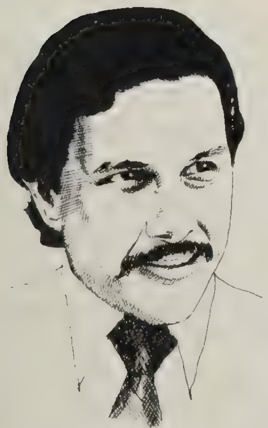

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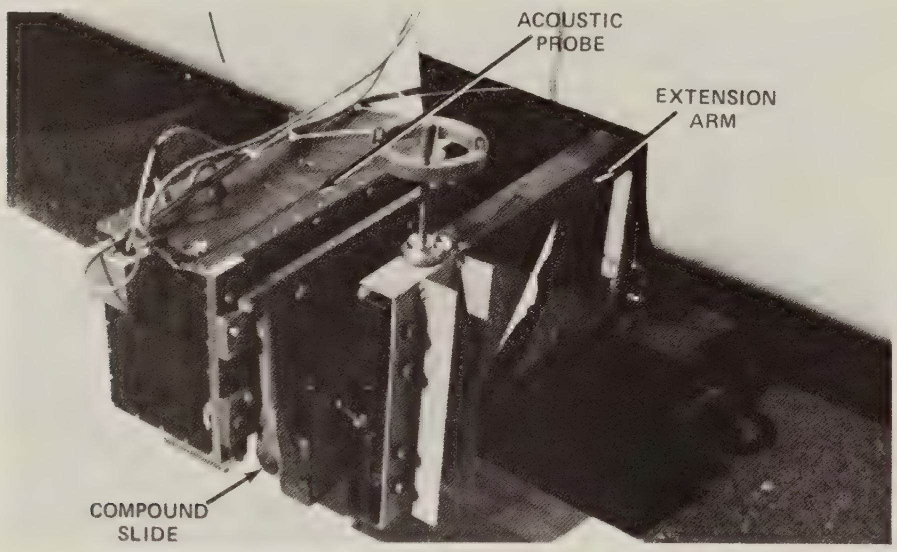
The Evaluation of a Noncontact Profiling System Using the Acoustic Probe



by
James C. Wambold[1]

This article evaluates the Rapid Travel Profilometer and describes how the four States owning a profilometer make use of it. From the States' experiences, filter and gain requirements for a profiling system are established. The operating principle of the noncontact profiling system is described, as are the following components: Acoustic probe, acoustic probe signal conditioning, vehicle body motion accelerometer, and the signal processing. A system evaluation procedure is presented with a discussion of operation experience and the difficulties encountered. The present system is usable; however, because of the many bench-type components in the system, further development to adapt it to over-the-road environment is recommended.

[1] This article is in part taken from "The Evaluation of a Noncontact Profiling System Using the Acoustic Probe," by James C. Wambold, Report No. FHWA-RD-78-43, *Federal Highway Administration*, Washington, D.C., March 1978.

Introduction

This article discusses a noncontact acoustic probe (AP), its phase measuring equipment, an accelerometer, and commercial integrating and summing analog equipment that were mounted and installed in a sports van to determine road profile. (*1*)[2]

The Rapid Travel Profilometer (RTP) uses two spring-loaded, road-following wheels instrumented with a linear potentiometer to measure relative displacement between the vehicle frame and the road surface of the two wheel tracks. (*2–4*) The RTP system is manufactured with instrumentation to measure vehicle frame motion. The frame motion is then added to the relative motions to yield two voltage signals which, in theory, are the road profiles of the wheel paths.

[2] Italic numbers in parentheses identify references on page 113.

The RTP system uses two accelerometers, each mounted on the frame over one of the follower wheels, to measure the vehicle frame motion. These acceleration signals are double integrated by an onboard analog computer and then added to the relative displacement signal to obtain the road profile signal (fig. 1). To accommodate various wavelengths at various road amplitudes, the RTP onboard computer is equipped with four selectable gains (0.2, 0.5, 1.0, and 2.0) and four selectable high pass filters (0.3, 0.6, 1.0, and 3.0 rad/sec).

In practice the amplitude is attenuated at the cutoff frequency, and there is phase shift of the signal as well. The amount of attenuation and phase shift depends on the order of the filter. Figure 2 is a plot of the typical phase shift and frequency response (amplitude magnification) of the four filters.

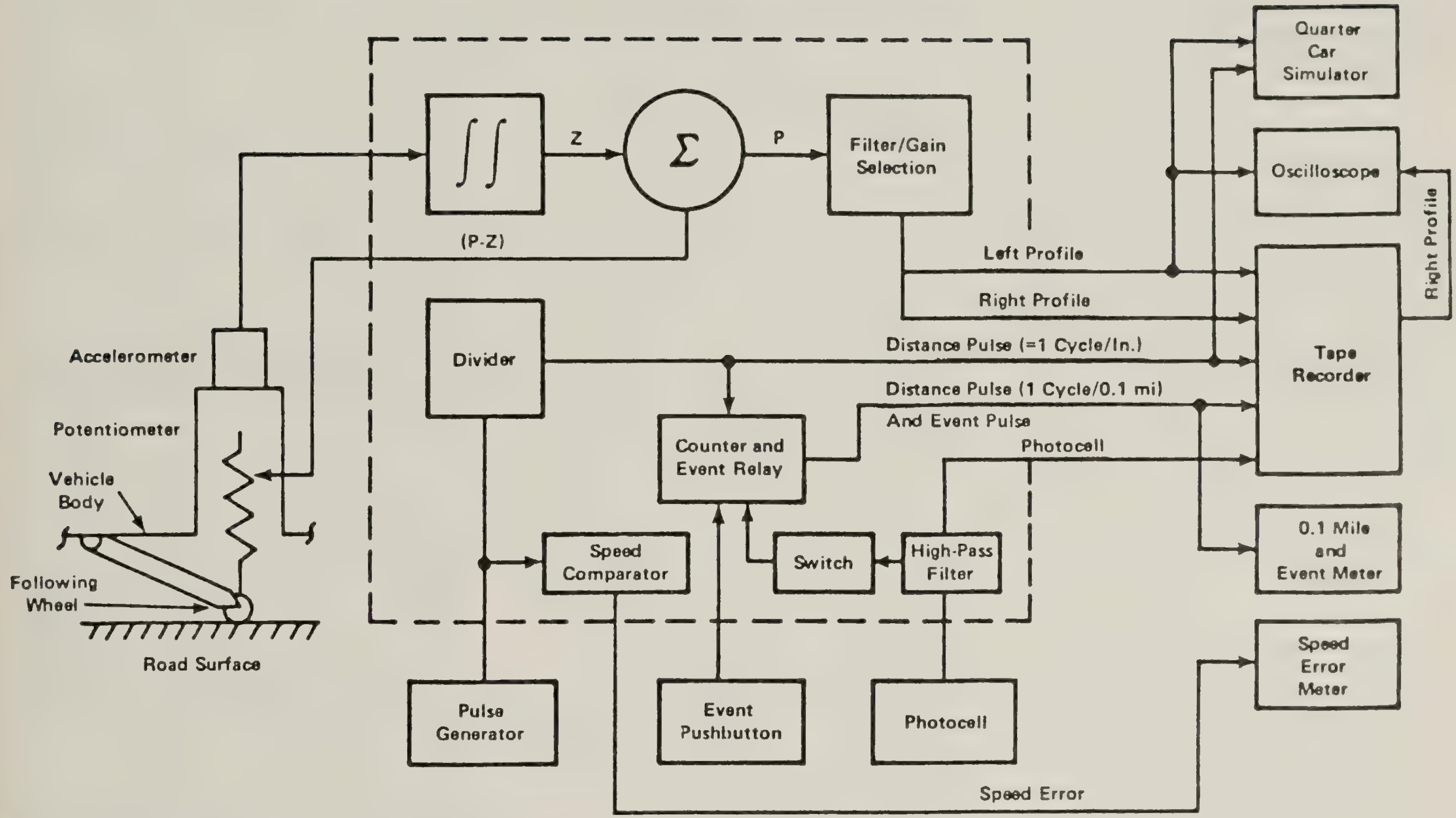
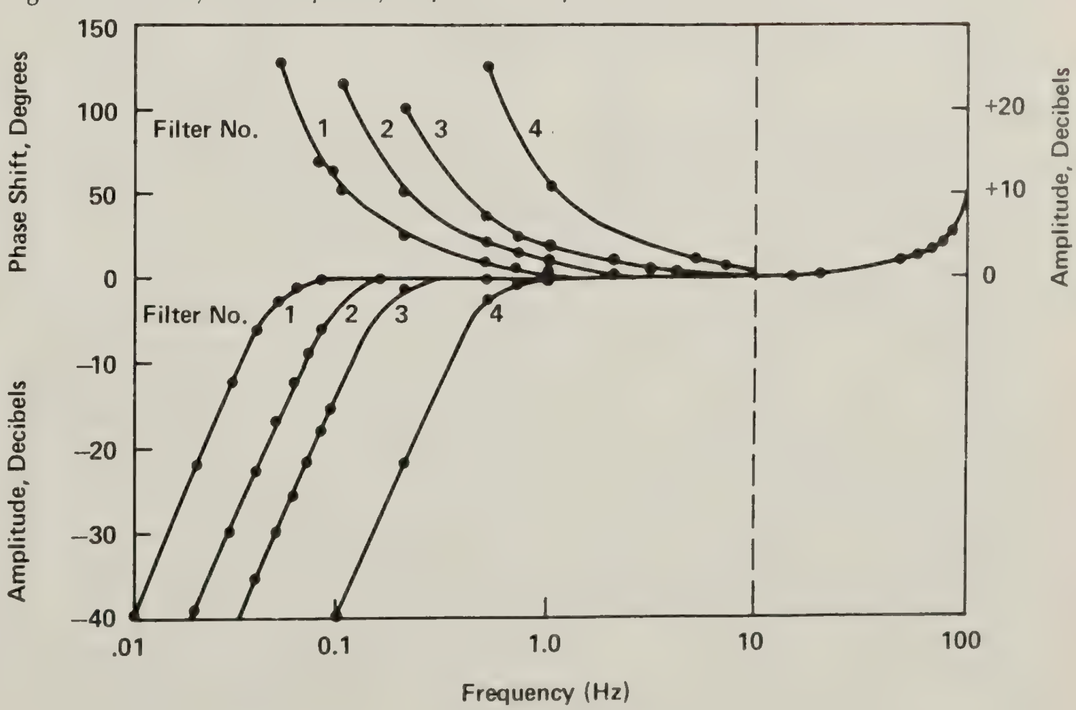


Figure 1.—Block diagram of measurement system for the RTP.

The main limitation of the RTP system is the road-following wheel. (*5, 6*) Because it is a mechanical dynamic system, frequency response and profiling speed are limited. Because of this weakness in the RTP, a noncontact probe was developed to replace the road-following wheel so the limitation on frequency response would be removed. (*1, 7*)

Figure 2.—RTP system frequency response and phase shift.



States Now Using the RTP

At present, Kentucky, Michigan, Pennsylvania, Texas, and West Virginia have RTP's. West Virginia has the newest RTP (purchased in the last year), in which all analog signals from the transducers are converted into digital signals and then all digital processing is performed onboard. All the other States have all analog models and have had them for 10 years or more.

Kentucky and Pennsylvania also have quarter-car-simulators (QCS) onboard that simulate the Bureau of Public Roads (BPR) roughometer and use the profile signal as input. (*8*) All of the onboard processing is analog, including the QCS. Texas has analog processing equipment to obtain profiles, but no QCS. Michigan has replaced its analog processor and is conducting its processing digitally—some onboard and some in the laboratory. The report referenced in footnote 1 briefly reviews how each of these four States uses its RTP.

Based on what the four States are presently doing with their RTP's, any new profilometers developed should have a selection of filters and gains as follows:

Gain: 0.5, 1.0, and 2.0

High Pass Filter Cutoff Frequency: 0.3, 0.6, 1.0, and 3.14 rad/sec

These selections are the same as those of the RTP except the 0.2 gain and No. 4 filter are not used. Michigan omitted the 0.2 gain and replaced the 3.0 rad/sec with a new No. 4 filter of 3.14 rad/sec.

These settings are required for both analog and digital processing. For analog processing, they are hardware items; for digital processing, they could be hardware, software, or, more likely, a combination.

Noncontact Profiling System

The noncontact profiling system consists of four major parts: (1) The AP to measure relative displacement, (2) phase measuring equipment to produce a voltage proportional to the relative displacement, (3) the accelerometer to measure the acceleration of the probe support, and (4) the analog processing equipment to double integrate the acceleration signal to produce a voltage proportional to the probe support motion and then to sum this with the relative displacement signal to produce a voltage proportional to the profile. In addition to analog processing, digital processing is available. For digital processing, the relative displacement signal and the acceleration signal are converted from analog to digital in the laboratory, and then a digital signal of the profile is produced by digital integration and summing.

The AP consists of a sound generator and receiver that face the road surface so that the sound transmitted by the generator reaches the receiver after being reflected from the road surface. The time delay of the sound wave arriving at the receiver is a function of the probe height above the surface. Changes in time delay due to changes in road-to-probe distance can be measured with great precision if the resulting phase angle change is measured. A complete description of the AP is given in references 1 and 7.

A low g range (± 15 g's) accelerometer with a d.c. to 500 Hz frequency was mounted on the AP body to measure the probe body motion. A signal conditioning unit was also used to obtain accurate acceleration data from the accelerometer. A 1.0 rad/sec RC high pass filter was inserted into the system after the signal conditioning unit. This filter was used to provide an a.c. coupling so that d.c. offsets in the signals are removed (in particular, a d.c. signal resulting from the accelerometer not being vertical).

To use the acceleration and AP data, the acceleration must be integrated twice to give body motion, the body motion signal and AP signal must be scaled to the same value, and then these two signals can be summed to produce a profile signal. This processing was done with analog equipment onboard the profilometer and digitally in the laboratory.

The onboard processing equipment is an analog system comprised of various modular elements: (1) A mainframe that provides all necessary power supplies, (2) two analog signal conditioning modules that accept the acceleration and AP signals, (3) two integrating modules that double integrate the acceleration to provide body displacement, and (4) a summing module to sum the double integrations with the AP signal to produce the road profile signal.

The analog equipment, accelerometer system, AP and its measuring equipment, a fifth wheel for speed measurement, and a separate slider (a linear potentiometer to measure relative motion for calibration purposes) were calibrated and installed in a van. Power supplies, an analog tape recorder, and a strip chart recorder were also added. Figure 3 shows the complete system's wiring. The integrator modules were modified by placing a 1.5 meg resistor across the integrating capacitor to give a 2 Hz high pass filter. This kept the amplifiers from saturating.

System Evaluation Procedures

The following four-task testing procedure evaluated the performance of the AP and established the operational characteristics.

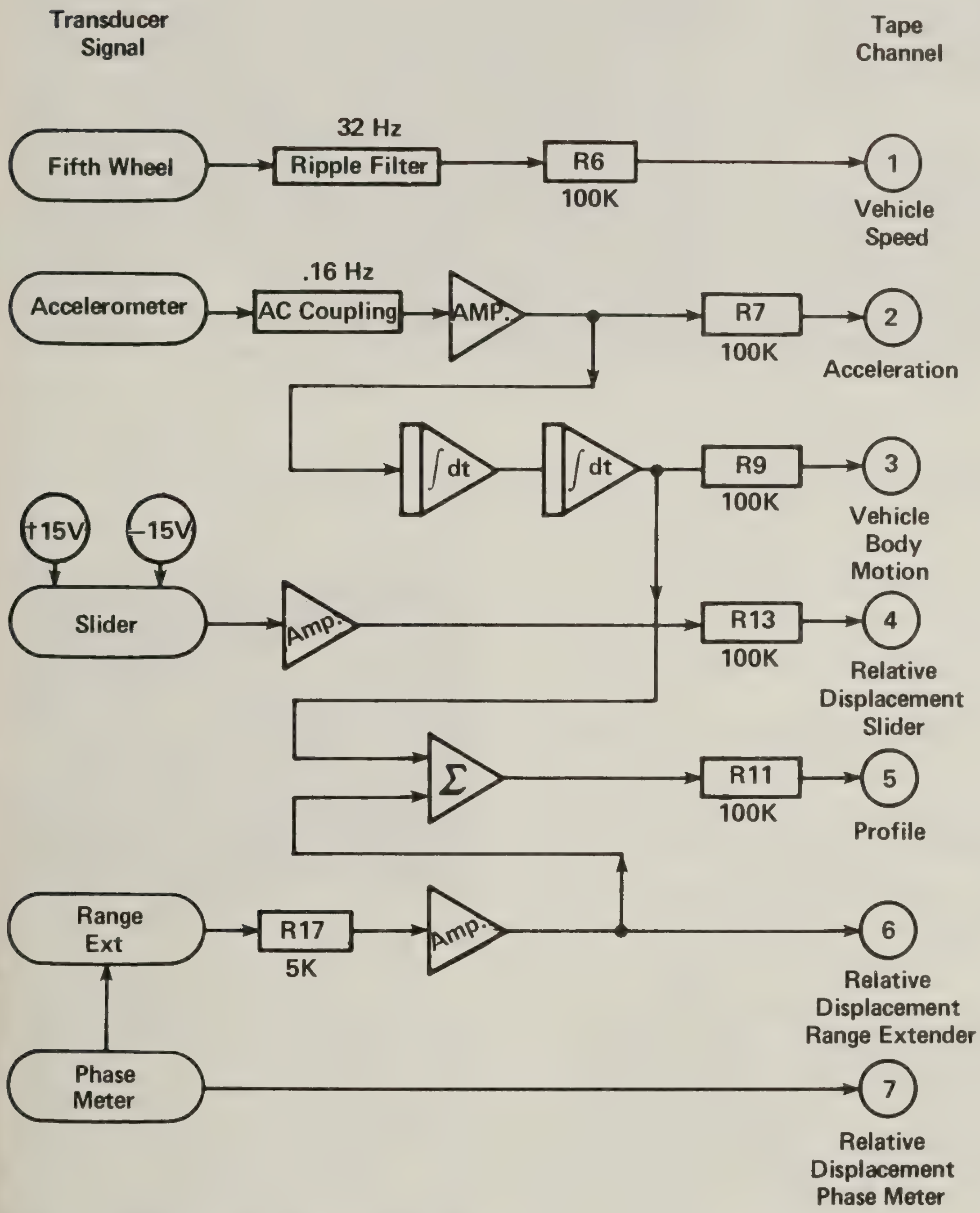


Figure 3.—Wiring of AP profiling system. R6, R7, R9, R11, R13, and R17 are trim potentiometers.

Task 1—Set up the AP for bench tests to evaluate precision and repeatability.

The laboratory evaluation included the following tests:

- Determine the phase shift and gains of the acoustic amplifiers and filters.
- Determine the sound levels.
- Test the linearity of the phase detector and range extender as a function of AP distance from the surface.
- Measure the footprint of the AP.

Task 2—Mount the AP, an accelerometer, and recording instrumentation on a vehicle to run exploratory tests.

The AP was mounted to the frame on the left side of a 1974 van. The AP was attached to the frame with a Secto travel compound slide so the probe could be positioned vertically and laterally. The AP was positioned to track in the path of the van's left wheels. Figure 4 shows the location of the AP mounting. Figure 5 shows the instrumentation mounted in the van.

A 0.5 by 15.2 m (1.5 by 50 ft) sandbox was built along the road at the Federal Highway Administration (FHWA) Fairbank Highway Research Station (FHRS), McLean, Va. Two plywood forms were made so sinusoidal wave shapes with wavelengths of 230 mm (9 in) at amplitudes of 10 and 20 mm (0.4 and 0.8 in) would be produced (fig. 6). The van was then driven with the AP extended over the sandbox.

These tests showed that, even at slow speeds, the van had enough body motion to invalidate the measurements. To account for body motion, an accelerometer was mounted on the AP body.

Figure 4.—1974 van with AP.

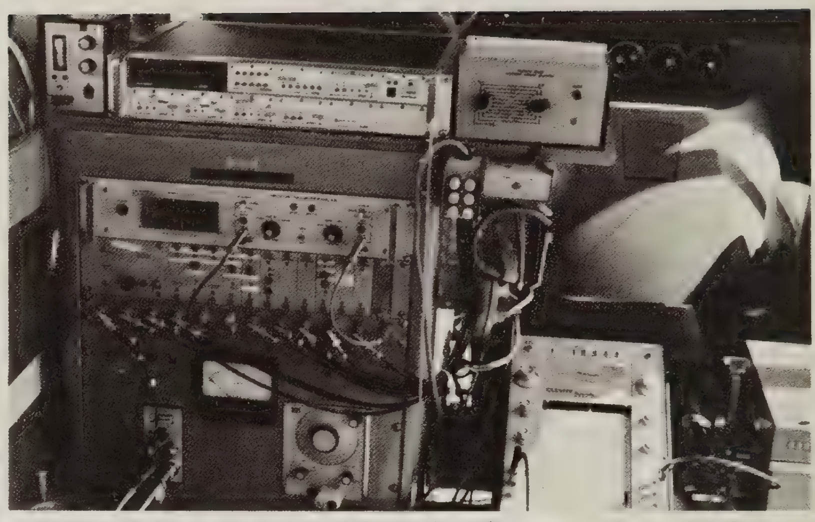


Figure 5.—Instrumentation mounted in the van.

Task 3—Run a dynamic calibration of the system.

To calibrate the van-accelerometer-probe system (AAP), a trailer hitch was added to the van and was connected by a rod to a hydraulic servo shaker. Tests were conducted at every 0.1 Hz from 0.5 to 1.0 Hz and at every 0.5 Hz from 1.0 to 7.0 Hz.

Task 4—Conduct road tests to determine repeatability and effects of testing variables.

For these tests, the system was operated on the road. First roads on the grounds of FHRS were profiled and then roads in the Washington, D.C., area were profiled, including the George Washington Memorial Parkway and the Dulles Access Road.

Preliminary Operating Experience and Difficulties

A number of tests were performed including static and dynamic laboratory tests and three sets of field tests to compare measured results with the RTP systems. (*1*) A summary of the difficulties encountered follows:

- Amplitude modulation of the sound signal.
- Irregular reflections of sound signals.
- Frequency response and slewing rate of phase meter.
- Signal loss and range extender dropout at some conditions.
- Components not able to withstand over-the-road use, in particular, vibration and wet weather.

However, the probe and the RTP road data compared favorably and the acoustic probe is capable of recording surface profiles at speeds of 26.8 m/sec (88 ft/sec) with a vertical height resolution of 0.25 mm (0.01 in).

The experiences and difficulties encountered by FHWA during the initial staff studies are given below.

Bench tests

The AP was tested and a report was issued describing the findings of the laboratory tests. A summary of the important findings is given here.

- The acoustic equipment had phase shifts that tracked within 2°, resulting in a distance error of about 0.25 mm (0.01 in).
- The system would experience dropouts with loss of signals, resulting in the range extender losing track of its count.
- The acoustic probe was blind to an object of one-half the wavelength of the acoustic signal.
- Sufficient information could not be found on the effects of and method to compensate for temperature variation.
- The system was quickly rendered inoperative by rain or wet pavements.

Figure 6.—View of the sandbox used to produce profiles.

In addition, it was concluded that "the noncontact probe as tested in the laboratory appears to present an interesting and promising technique for the measurement of distance between itself and a road." It is also recommended that a minimum field test program be undertaken with frequent data review by a committee and, following evaluation, a Request for Proposal be issued for the further development of the probe.[3]

Exploratory sandbox tests

The sand tests were intended to be exploratory and showed that the vehicle body motion must be known for any measurement. No qualitative results were obtained because body motions were not measured. The use of the sandbox is an excellent test method and is recommended for use in further tests, but the sandbox should be at least 30 m (100 ft) long.

Dynamic calibration

This test provided the most useful information. Unfortunately, the measurements made with a ruler were not made at every data point because these measurements were only made to calibrate the linear potentiometer (slider) which was used as the reference signal. Because the slider was only attached to the vehicle and not to the ground, ground contact was lost at higher frequencies, which invalidated the slide as a reference at higher frequencies.

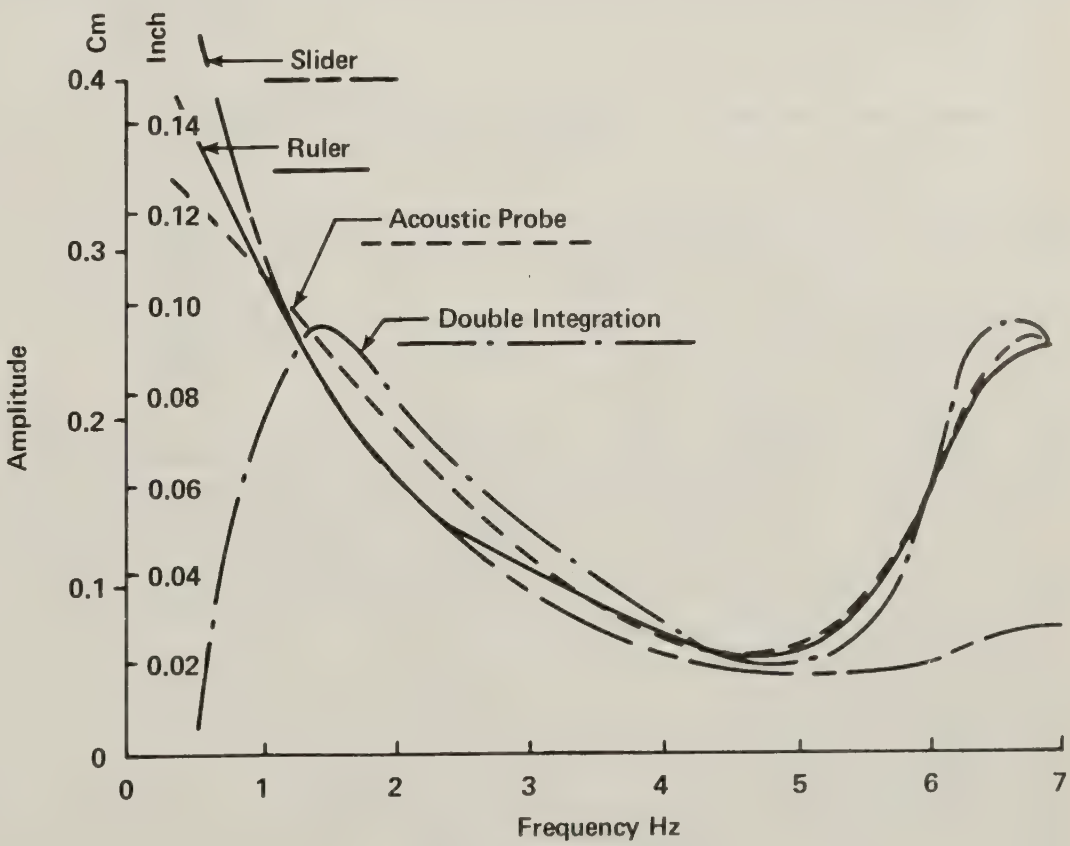
Amplitude levels

Both amplitude and phase shift were determined in the dynamic tests. Because of the many voltage dividers added to the system, the overall gains were not known and are determined from these calibration tests. Figure 7 is a result of matching the various signals to the ruler measurements. Good agreement of the slider signal is obtained up to about 5 Hz. Above this frequency, the effect of the slider losing ground contact is very obvious. The probe signal agrees very well with the ruler; in fact, at all data points, the probe signal passes through every point except 0.4 Hz. Similarly, the double integration signal agrees well above 1.5 Hz. Because the integrators were modified to create a high pass filter, the attenuation of the signal below 2 Hz is to be expected. In fact, the high pass filter modification was set for a 2 Hz cutoff.

Phase shift

Unlike the calibration of amplitude levels, the actual phase shift could not be determined because there is no reference signal for comparison. Figure 8 is a plot in which the slider is assumed to have no phase shift up to 2 Hz and the range extender and double integration signals are assumed to have no phase shift above 5 Hz. A smooth transition of the slider is assumed between 2 and 5 Hz. Theoretically, the acceleration signal is passed through a high pass RC filter set at 1.0 rad/sec (0.16 Hz) so that one would expect it to start at a 90° phase shift and go to 180° around 4 rad/sec (0.63 Hz). The shift between the range extender and integration does go to zero above 5 Hz. Thus, the sum of the two signals would be expected to add properly in this

Figure 7.—Comparison of the four displacement measurements over frequencies of 0.5 to 7 Hz.



[3]"Report on the Laboratory Evaluation of the Acoustic (Noncontact) Probe," by Joseph C. Leifer, Nov. 10, 1975. Unpublished report.

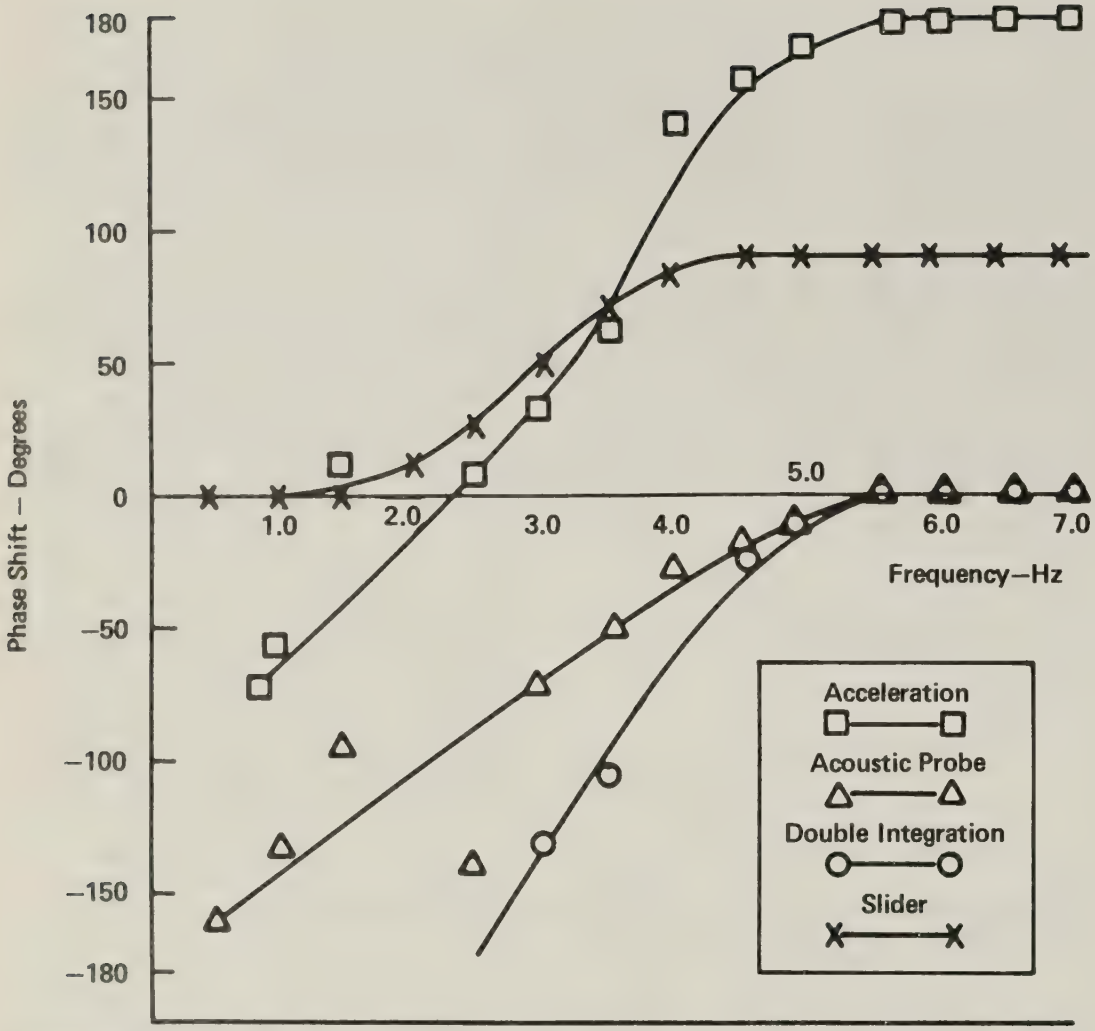


Figure 8.—Phase shift comparison with slider used as zero shift at low frequencies and the AP used as zero shift at high frequencies.

range. Below 5 Hz, the phase shift causes improper addition, but, again, this will be corrected by lowering the cutoff frequency from 2 Hz to 0.16 Hz or lower. In fact, there are phase shifts among all the signals measured and their sources must be determined.

Conclusions

The prototype of the AP was used in a series of in-house tests to (1) familiarize research and development (R&D) personnel with its operation and establish its operational characteristics, (2) evaluate it by static and dynamic testing, and (3) evaluate data processing methods.

Familiarization and operational experience

FHWA R&D personnel have now had 2 years of experience with the AP and about 1 year with the analog data processing equipment. Adequate experience has been obtained to evaluate the AP and analog data processing.

Evaluation of the acoustic probe

In evaluating the AP, one must remember that this is a prototype and many of the components are laboratory-type equipment and are not designed for on-the-road use. Although the prototype does not operate under certain environmental conditions, there was enough operating experience to evaluate the operating principle.

The physics of using the AP method to measure distance is sound, and testing has shown that the AP is able to measure distance accurately. Further, the AP can be made to work as part of a noncontact profilometer. There are some problems with the present prototype, but they can be solved. The present shortcomings of the probe follow, along with a discussion of possible solutions:

- Periodic signal loss results in the range extender losing track of its count.
- The footprint area is not well defined.
- Compensation for temperature is not made completely.
- Components are not made to withstand on-the-road use, particularly on wet roads.
- The AP cannot measure objects one-quarter the wavelength of the signal.
- There is signal interference from outside noise, such as aircraft, wind, and other traffic.

Although most of the dropout in earlier tests (laboratory and sandbox tests) was found to be a broken lead in a microphone cable, periodic dropout does occur; one reason is the AP's inability to measure objects one-quarter the wavelength of the signal. The causes of signal loss need to be studied further to minimize or eliminate signal loss either directly or in the computer processing. One method that seems to eliminate signal loss is frequency modulation of the acoustic signal. This allows for a signal of much lower frequency (and longer wavelength) to be used with a much higher carrier frequency. The advantages of this include the following:

- The range extender could be eliminated because the signal wavelength could be adjusted to the required height. Then if the signal was lost, position would be known when the signal was reestablished.
- The carrier frequency could be set to optimize reflection and minimize signal loss.
- The higher frequency used to optimize reflection, along with the FM rather than AM signal, would greatly reduce the influence of noise.

Evaluation of data processing

The analog equipment cannot cope with any signal bias because double integration of even a small offset soon overloads the output. The initial filtering placed on the integrators solved this problem, but it also filtered out the signal in the frequency of most concern. The cutoff frequency will need to be lowered by an order of magnitude. Analog double integration is presently performed by the RTP and by the Simple Survey Profilometer (SSP). (*9*) In fact, the SSP uses the same analog equipment, so a satisfactory double integration is possible.

Acknowledgment

The author would like to thank the Electronic Instrumentation Group, Engineering Services Division, FHWA, for its assistance in the laboratory evaluation of the acoustic probe.

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(*5*) J. R. Karlington and P. A. Milliman, "A Progress Report on the Evaluation and Application Study of the General Motors Rapid Travel Profilometer," Highway Research Record 214, *Highway Research Board,* Washington, D.C., 1968.

(*6*) W. Ronald Hudson, "High-Speed Road Profile Equipment Evaluation," Research Report 73-1, *The University of Texas,* Austin, Tex., January 1966.

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James C. Wambold is an associate professor of mechanical engineering at the Pennsylvania State University. He has been involved in research on vehicle/road interaction for the past 12 years. Dr. Wambold's interests include random vibration, vehicle dynamics, and ride comfort. He has also been involved in road roughness measurement. He recently spent a 9-month sabbatical leave with the Protective Systems Group, Structures and Applied Mechanics Division, Federal Highway Administration.

Laboratory Studies of Lane Occupancy Signs

by
Donald A. Gordon[1]

Introduction

Many signing problems may be studied conveniently in the laboratory. The advantage of laboratory research is that a large number of signs can be quickly and inexpensively investigated. Also, control can be maintained over illumination, sign pattern, and driver training and experience that is not possible in the operational situation. Drivers' opinions of the signs can be conveniently solicited and subtle differences in sign effectiveness can be revealed. For these reasons, laboratory tests are particularly useful for preliminary sign testing. However, the design and improvement of signs is best achieved by a balanced program including both laboratory and field research.[2] Whenever possible, the laboratory findings should be validated by field tests.

The Traffic Systems Division, Federal Highway Administration (FHWA), is now conducting an in-house study on the improvement of highway signs. Included are laboratory studies on the improvement of lane occupancy signs. Research on parking signs will be described in the next issue of *Public Roads*. In the lane occupancy sign studies, the experimental subjects viewed slides of conventional and novel signs and judged whether certain lane occupancy maneuvers were permitted. The effectiveness of each sign was determined by the speed and accuracy of the subjects' responses.

Lane Occupancy Signs

Lane occupancy (lane control) signs show the driver the particular lanes of a highway within which he or she may drive. Currently approved devices for lane control include signals showing a green downward-pointing arrow over permitted lanes and a red X over prohibited lanes. Fixed schedule signs that list occupancy

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[1] This article is a condensation of the report "Regulatory Signs for Lane Occupancy and Parking," by D. A. Gordon, Report No. FHWA-RD-78-89, *Federal Highway Administration*, Washington, D.C., June 1978.

[2] T. Mast, "Alternative Techniques for Testing Highway Information Systems." Paper presented at the American Institute of Aeronautics and Astronautics Systems Conference, Arlington, Tex., Nov. 6-8, 1974.

information for the entire day are also used. In the lane occupancy sign studies, the following sign series were assessed: Series 1—fixed schedule signs now on the road, Series 2—printed message signs (without schedule), Series 3—signs showing the red X and green arrow symbols similar to the red and green "signals" approved by the Manual on Uniform Traffic Control Devices (MUTCD),[3] and Series 4—a design developed under FHWA sponsorship at Texas A&M University.[4] Forty subjects viewed these signs in the laboratory and judged whether the signs permitted certain lane maneuvers.

Subjects

Subjects for the study were recruited from the Virginia State Employment Office and from FHWA's Fairbank Highway Research Station (FHRS), McLean, Va. The sample of 40 subjects included an approximately equal number of males and females and a range of ages, education, and driving experience. All subjects had valid driving permits.

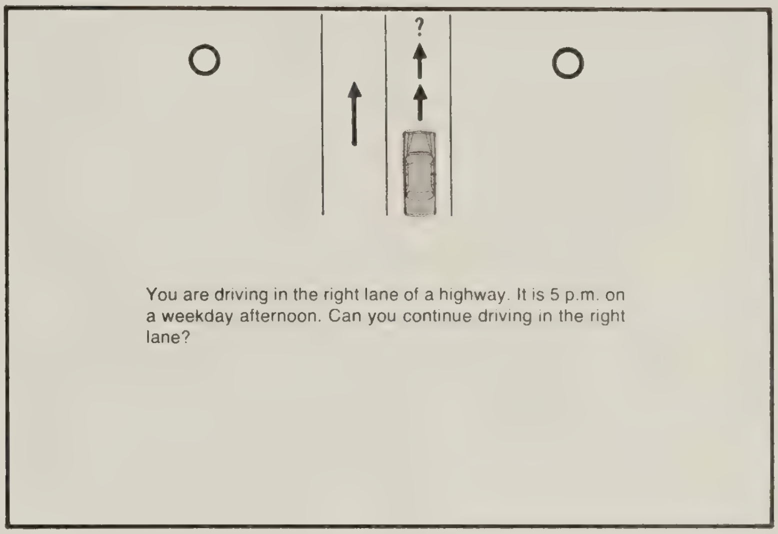


Figure 1.—A lane occupancy problem.

Equipment

Question booklets

Lane occupancy problems were presented to the subjects on library-style cards, fastened to rings (fig. 1). The problem stated the lane presently occupied by the driver and the time of day and asked whether a certain maneuver was permitted. Each problem was illustrated by a diagram of the road situation. When the subject said, "Ready," the road sign was projected on the screen. After answering a question, the subject turned to the next card. The same 22 questions were asked on each of the four sign series.

The sign series

Examples of the four sign series under consideration are shown in figure 2. Series 1 consisted of nine replicas of fixed schedule signs located around Chain Bridge, Va.; Telegraph Road, Va.; and Connecticut Avenue, Washington, D.C. These signs are representative of fixed schedule lane occupancy signs in the Washington, D.C., area.

Series 2 signs presented the same regulations as Series 1 in the form of printed instructions, such as "Right Lane Only," "Through Traffic Either Lane," and "Left Lane Closed." The rules shown were those in force at the time given in the corresponding Series 1 question.

Series 3 changeable message signs presented the MUTCD-approved red X and green arrow symbols. Series 4 changeable message signs indicated lane status by the words "closed" or "open." Where necessary, printed messages were used.

[3]"Manual on Uniform Traffic Control Devices for Streets and Highways," *National Advisory Committee on Uniform Traffic Control Devices, U.S. Department of Transportation,* Washington, D.C., 1978.

[4]C. Dudek, R. Hutchinson, R. Koppa, and M. Edwards, "Human Factors Evaluation of Traffic State Descriptor Variables: Vol. 9—Human Factors Requirements for Real-Time Motorist Information Displays," Report No. FHWA-RD-78-13, *Federal Highway Administration,* Washington, D.C. Report not yet published.

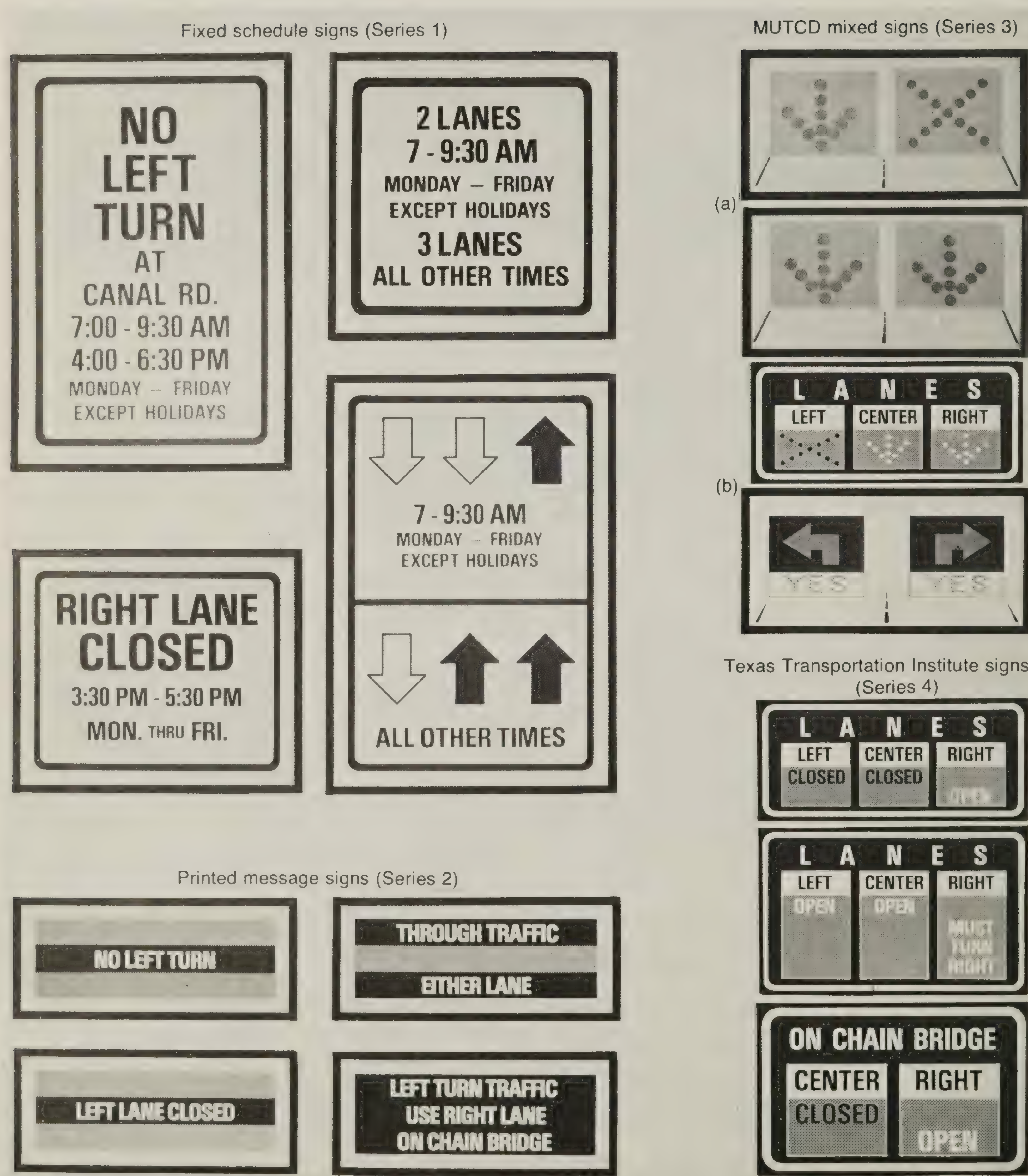


Figure 2.—Signs used in the lane occupancy study.

Procedure

The slides were projected on a screen 0.52 m high by 0.49 m wide (1.7 ft by 1.6 ft), 0.61 m (2 ft) in front of the subject (fig. 3). The subject viewed the sign and signaled his or her answer by pressing the "yes" or the "no" button on a console. The subject's response was indicated on the experimenter's console by coded lights; response time appeared on a digital timer. The timer started when the sign was projected on the screen and stopped when the subject responded. After each response, the experimenter reset the timer and showed the next sign when the subject said, "Ready."

Twenty-two questions were asked on each sign series. The answers to these questions and the associated response times constituted the experimental data of the study.

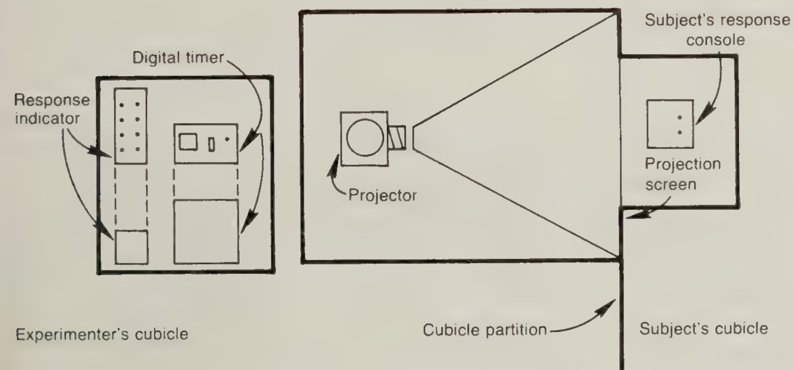


Figure 3.—Schematic diagram of the experimental setup.

Results

Table 1 presents a summary of the experimental results. The effectiveness of the tested sign series is indicated by the errors and response times. Each number in table 1 is based on 880 separate responses by the 40 subjects to the 22 questions.

Errors

An error was made when a subject's response violated the lane occupancy instructions shown on the sign. Table 1 shows that 143 errors were made on Series 1 signs; 20, 16, and 8 errors were made on the three changeable message sign series. These results indicate 1 error for every 6.15 presentations of Series 1 signs, and 1 error per 44, 55, and 110 presentations for the three changeable message sign series. The changeable message series signs elicited considerably fewer errors than the Series 1 signs. In all three comparisons between fixed schedule and changeable message series, the differences found in the number of errors would have occurred by chance less than once per 100,000 replications of the study (Binomial Expansion Test). The fixed schedule sign average of 1 error per 6.15 trials represents a dangerous performance that could lead to an accident.

Among the changeable message signs, the printed message signs (Series 2) produced more errors than the MUTCD-approved (Series 3) or Texas A&M (Series 4) signs. But none of the differences among the changeable message series reached a 0.05 level of statistical significance.

Table 1.—Lane occupancy study results

	Sign series			
	1	2	3	4
Total errors	143	20	16	8
Mean errors per question	0.163	0.023	0.018	0.009
Mean trials per error	6.15	44.0	55.0	110.0
Mean response times (seconds)	5.49	2.44	1.84	1.81

Response Times

On the average, subjects took more than twice as long to respond to Series 1 signs than to respond to any of the other sign series (table 1). The superiority in response time of each of the changeable message series over the fixed schedule sign series would occur by chance less than once per million replications of the study. The subjects' response times to the changeable message series may be regarded as minimal; a driver on the road would require more time to make a judgment than did the subjects performing in the laboratory.

In Series 1, 16 of 22 questions had 25 percent or more subject errors or dangerously delayed responses (longer than 10 seconds). None of the responses for the changeable message sign series was as much as 25 percent faulty. Differences between the Series 1 signs and any one of the changeable message series signs would occur by chance less than once per million replications of the study.

Drivers' Appraisals of the Signs

After completing the lane occupancy questions, subjects were asked to rank and rate each sign series. Sign Series 3 was divided into a and b, shown in figure 2. To help them rank the sign series, subjects were shown examples of the signs that they had responded to earlier in the experiment. These signs were shown as often as requested by the subject. Ranking data were obtained from 21 subjects.[5]

The results in table 2 show that the fixed schedule signs were ranked lowest by 19 of the 21 subjects. The mean rankings were obtained by weighting each rank by its associated frequency and dividing the total by the 21 responses. The Series 1 fixed schedule sign had an average ranking of 4.71 on a 5-point scale where 1 was high and 5 was low. Printed messages were ranked lowest of the changeable message types.

Table 2.—Rankings of sign series

Sign series	Rank 1	2	3	4	5	Mean rank
1	1	0	1	0	19	4.71
2	5	0	4	12	0	3.09
3a	8	5	5	3	0	2.14
3b[1]	1	11	4	3	1	2.60
4[1]	6	4	7	3	0	2.36

[1] In one instance there was a tie between second and third place. Both signs were ranked 2.5.

Rating results conform with the rankings (fig. 4). To rate the series, each subject marked his or her assessment on a printed scale. The lines shown in figure 4 indicate the range of subjects' ratings from the first to the third quartile. The dot on the line shows the median rating.

[5] Data are not available for the remaining 19 of the 40 subjects.

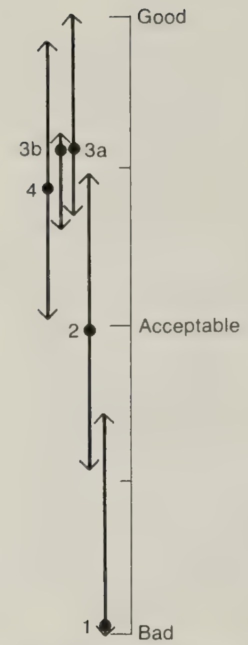


Figure 4.—Ratings of sign series—the median rating is shown by a dot; the 25th and 75th percentile ratings are shown by arrow extremes for each rated series.

The median rating of changeable message sign Series 3a, 3b, and 4 fall between "acceptable" and "good." The median rating of the printed message Series 2 signs is slightly below "acceptable." Series 1 fixed schedule signs are rated close to "bad."

Subjects spontaneously expressed difficulties with the fixed schedule signs. Typical reactions were as follows:

> "The first kind, that is the kind they have in D.C., I can't go there. I get so confused with the lanes. I have somebody come with me." (Subject 38)
>
> "It's too mind boggling to figure the times and the exceptions." (Subject 36)
>
> "It takes too long to read." (Subject 33)
>
> "The changeable messages are so much easier to read than these signs." (Subject 32)
>
> "These are the ones that just throw me." (Subject 26)
>
> "I just can't react that fast to a written sign." (Subject 25)
>
> "You don't have time to read a whole sign. That's why symbols are better." (Subject 24)
>
> "Bad. I hate those signs." (Subject 21)
>
> "Should be discontinued. You have to stop to understand it." (Subject 18)

Discussion

These laboratory results demonstrate the advantages of changeable message signs over fixed schedule lane occupancy signs. Changeable message signs give more accurate responses, are more quickly interpreted, and are preferred by drivers.

Among changeable message signs, the Series 3 MUTCD-approved red X and green arrows and the Series 4 Texas A&M design were more effective than the Series 2 printed message signs. Series 3 and 4 signs had fewer total errors, shorter response times, and were more highly ranked than the Series 2 signs. The Texas A&M sign format has the additional advantage of being able to show incident messages such as "right lane closed," "closed accident," and "must turn right," in addition to the "open" and "closed" lane occupancy messages tested in this study. To reduce installation costs, it would be advantageous to display occupancy information in the highway shoulder-mounted position. On-the-road field studies would be required to test the practicality of this technique.

These lane occupancy sign studies raise questions on the use of fixed schedule occupancy signs. Incorrect judgments were made 7 times more often on the fixed schedule signs than on any of the changeable message series—1 error per 6.15 presentations. Subjects took more than twice as long to interpret fixed schedule signs than to interpret signs in the other series. Twenty-five percent or more wrong responses or dangerously delayed responses (longer than 10 seconds) were given on 73 percent of the fixed schedule signs. Drivers mentioned difficulties they had experienced with the fixed schedule signs now on the road; these signs were rated "bad" by more than half of the subjects. The effectiveness of fixed schedule lane occupancy signs should be examined further in field studies. Possibly such signs need to be replaced by low-cost changeable message signs, yet to be developed.

Donald A. Gordon is a research psychologist in the Traffic Systems Division, Office of Research, Federal Highway Administration. He has been involved in research on the driving process and the development of improved signs and roadway delineations. He has published articles on topics such as perception in vehicular guidance, experimental isolation of the driver's visual input, and the contribution of psychology to the traffic flow theory. Lately, he has been concerned with the development of improved highway guide signs.

Recent Research Reports You Should Know About

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 Division. The reports are available from the address noted at the end of each description.

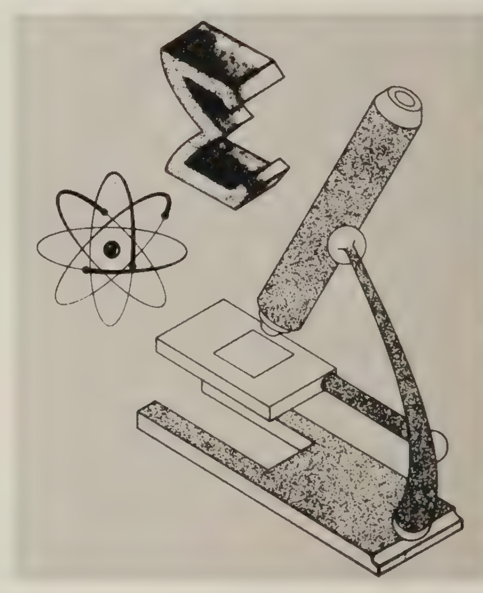
Technical Guidelines for Expansive Soils in Highway Subgrades, Report No. FHWA-RD-79-51

by FHWA Materials Division

Volume change of expansive soil subgrades resulting from moisture variations causes highway damage estimated at $1.7 billion annually. This report concludes a 4 1/2-year study to evaluate methods for predicting and minimizing detrimental volume change of expansive soils in highway subgrades. The report presents technical guidelines for: Locating potentially expansive soil areas using occurrence and distribution maps; exploring and sampling expansive soils in the field; identifying and classifying potentially expansive soils using index and soil suction properties; testing expansive soils and predicting volume change; selecting appropriate treatment methods; and presenting design, construction, and maintenance recommendations for new and existing highways.

Appendixes to the report describe the soil suction test procedure, a standard procedure for odometer swell tests, a procedure for calculating the potential vertical rise (PVR), and standards for field monitoring data. A bibliography of alternative treatments is included.

The report is available from the Materials Division, HRS-21, Federal Highway Administration, Washington, D.C. 20590.



Power Plant Bottom Ash in Black Base and Bituminous Surfacing, Executive Summary (Report No. FHWA-RD-79-72) and Users Manual (Report No. FHWA-RD-78-148)

by FHWA Materials Division

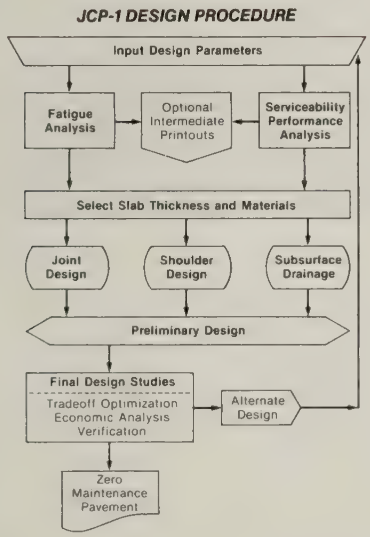
Because of dwindling supplies of natural aggregates in some areas of the United States and increasing shipping costs, the use of bottom ash and other waste substitutes in bituminous paving mixtures is being explored. The increasing use of coal is producing a great amount of bottom ash. Acceptable use of this waste material for highway construction would alleviate the economic and environmental problems confronting power plants having large amounts of this waste. These reports present the findings of an investigation of the use of bottom ash as a partial replacement or extender of natural aggregate in bituminous highway paving mixtures. The ash samples subjected to laboratory screening tests generally met specification requirements for an aggregate in bituminous mixtures.

Both dry and wet bottom varieties of the ash are described in the reports. Results of Marshall testing of bituminous mixtures containing varying proportions of ash and natural aggregate are presented. These results are compared with Marshall testing of bituminous mixtures containing only natural aggregate or bottom ash.

The reports are available from the Materials Division, HRS-23, Federal Highway Administration, Washington, D.C. 20590.

Design of Zero-Maintenance Plain Jointed Concrete Pavement, Volume I (Report No. FHWA-RD-77-111) and Volume II (Report No. FHWA-RD-77-112)

JCP-1 DESIGN PROCEDURE



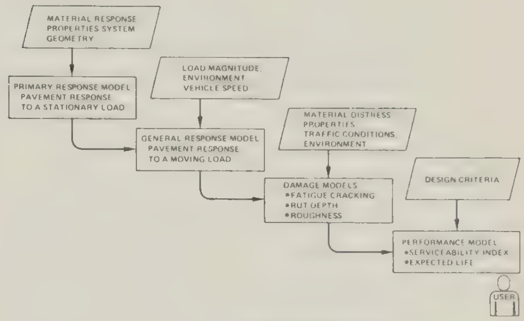
by FHWA Structures and Applied Mechanics Division

By definition, a zero-maintenance pavement does not require structural maintenance such as patching, crack or joint filling, slab replacement, grinding, or overlay during the initial design life.

Volume I, **Development of Design Procedures,** documents procedures for the structural design of plain jointed concrete highway pavements to provide zero-maintenance service under heavy traffic over a selected design period. The design procedures are based on nationwide field studies, long term performance data of inservice pavements, comprehensive mechanistic analyses, and laboratory studies. Both a serviceability-performance analysis and a concrete fatigue damage analysis are used to develop procedures for the structural design of the concrete slab, subbase, shoulders, joints, and subsurface drainage. Stresses in the slab resulting from traffic loading and from thermal gradients are considered in the analysis through use of a finite element model. A new serviceability-performance design model was derived for plain jointed concrete pavements based on long term performance data on sections of the American Association of State Highway Officials Test Road which have continued in service.

Volume II, **Design Manual,** is an engineering guide for the design of heavily trafficked plain jointed concrete pavements to provide zero-maintenance performance over a given period. Recommendations are made for obtaining necessary structural design inputs. A detailed design example is provided, which includes sensitivity and incremental cost analyses of the major design factors. Input and output listings are included for the computer program (JCP-1) written for the structural design of the pavement.

These reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 289394 and PB 289395).



MODULAR STRUCTURE OF VESYS

Effects on Flexible Highways of Increased Legal Vehicle Weights Using VESYS IIM, Report No. FHWA-RD-77-116

by FHWA Structures and Applied Mechanics Division

This report describes a study that established a predictive model for relating flexible pavement life-cycle costs for 20 years of acceptable service life to incremental increases in allowable axle load limits.

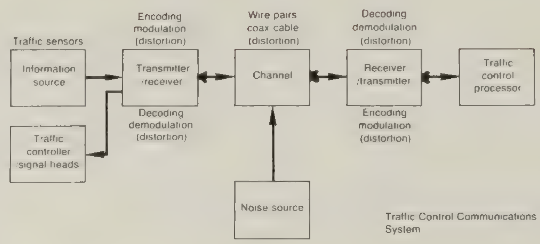
VESYS IIM, a computerized routine developed by FHWA for the analysis and design of flexible pavements, accepts input data describing the pavement structure, traffic loadings, temperatures, and seasonal material characterizations that reflect the pavement's environment. The results are predictions of fatigue cracking, rut depth, slope variance, the Present Serviceability Index, and expected life as a function of time in terms of truck traffic and axle load distribution.

The effects of four single-axle load levels—80, 89, 98, and 107 kN (18, 20, 22, and 24 kips)—and two levels of truck traffic volume were evaluated for two pavement thicknesses and four environmental zones—wet/freeze, dry/freeze, wet/no freeze, and dry/no freeze. When calculated pavement failures for the assumed design occurred in less than 20 years, trial overlays were introduced into the analysis and new life expectancies were predicted until a total pavement life of at least 20 years was attained. The costs of initial and overlay construction were estimated and related to the various axle load limits for 20 years of pavement service.

This analytical procedure was verified by comparisons of predicted and actual distress in 12 flexible pavement test sections throughout the United States. Performance and cost data are presented in the report for examples of both new and existing typical flexible pavements. The procedure and quantitative relationships are sufficiently accurate for useful pavement life analyses until more comprehensive procedures are available.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 289697).

A Communications Trade Off Study for Computerized Traffic Control, Volume 1 (Report No. FHWA-RD-78-85) and Volume 2 (Report No. FHWA-RD-78-86)



Traffic Control Communications System

by FHWA Traffic Systems Division

This report describes communication techniques that will reduce costs of future computerized urban traffic control systems. The information is presented in the form of reference material, cost computation procedures, and a communication subsystem specification example.

Volume 1, **Final Report,** discusses the principal functions of a computerized traffic control system, describes the types of data that must be transmitted, reviews the available communication methods, and shows how to estimate the transmission rate requirements for typical systems. It also discusses factors affecting communication costs and describes procedures for computing costs and utility measures. Volume 2, **Appendixes,** provides additional detailed technical information.

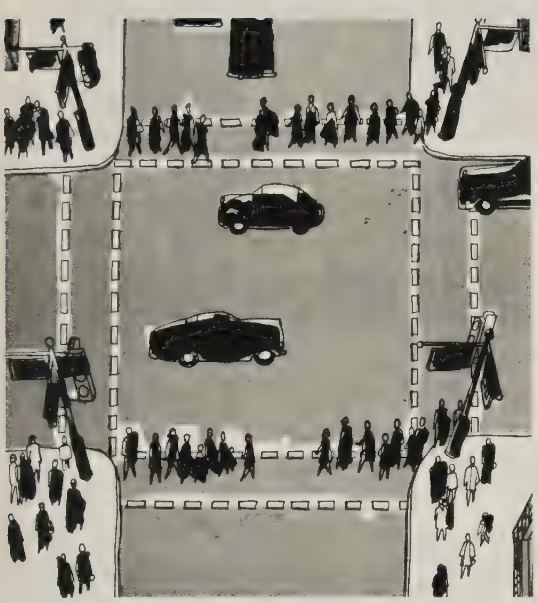
The reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 298843 and PB 298844).

Evaluation of Highway Advisory Radio in the I-35W Traffic Management Network, Report No. FHWA-RD-79-33

by FHWA Traffic Systems Division

This report presents the Minnesota Department of Transportation's experiences with and assessment of highway advisory radio (HAR) in a traffic surveillance and control network. The report describes HAR system hardware, its integration with traffic management operations, and its effectiveness as a traffic control device and covers the installation and operation of HAR for a 1-year period. An analysis of major system elements, message characteristics, motorist use and acceptance, and various system costs was made from the evaluation data.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 297142).



A Pedestrian Planning Procedures Manual, Volume I (Report No. FHWA-RD-79-45), Volume II (Report No. FHWA-RD-79-46), and Volume III (Report No. FHWA-RD-79-47)

by FHWA Environmental Division

This three-volume manual identifies relevant data, procedures, and criteria for planning and evaluating comprehensive pedestrian systems and individual facilities.

Volume I, **Overview,** provides a general background and introduction to the pedestrian planning process. Volume II, **Procedures,** describes operational methods which may be used for estimating pedestrian demands and evaluating pedestrian networks. Volume III, **Technical Supplement,** explains the derivation of the information provided in Volume II and presents detailed data and methodologies for various tasks. Illustrative examples are included.

The reports are available from the Environmental Division, HRS-41, Federal Highway Administration, Washington, D.C. 20590.

Highway Air Quality Impact Appraisals, Volume I (Report No. FHWA-RD-78-99) and Volume II (Report No. FHWA-RD-78-100)

by FHWA Environmental Division

Although much is known about air pollution, it has not been a major consideration in transportation planning. These reports guide transportation planners and engineers in performing air quality analyses and in incorporating air quality considerations into the highway planning and design process.

Volume I, **Introduction to Air Quality Analysis,** presents information for analyzing local or regional air quality impacts. It is useful as a general reference, particularly in the areas of emissions, atmospheric processes, and air quality models.

Volume II, **Guidance for Highway Planners and Engineers,** discusses air quality issues that arise in evaluating land use plans, transportation policies, and facility and operation plans at both regional and subregional levels. It familiarizes the highway developer with issues that must be considered in determining the appropriate analysis method. Laws that require air quality evaluations are reviewed.

The reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 293798 and PB 293799).

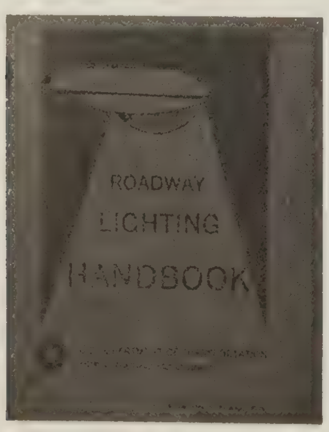
Implementation/User Items "how-to-do-it"

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, Office of Development, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies.

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

Items available from the Implementation Division can be obtained by including a self-addressed mailing label with the request.

Roadway Lighting Handbook, Implementation Package 78-15



by FHWA Implementation Division

This comprehensive, up-to-date handbook on public roadway lighting is intended as a guide in planning, designing, operating, and maintaining roadway lighting systems. It may be used as a reference document by engineers and public officials or as a textbook for formal education and training in roadway lighting. The overall process of designing and operating a roadway lighting system consists of several well-defined steps, which are identified as chapters in the handbook. International source material is incorporated.

The handbook is available for $4.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-003-00339-5).

Model Pedestrian Safety Program, Users Manual, Implementation Package 78-6

by FHWA Implementation Division

Local governments and the highway safety community are recognizing the magnitude and severity of the pedestrian accident problem. It is important to disseminate the latest information on accident reduction methods in a format readily usable by local officials. This manual provides comprehensive information on pedestrian accident reduction techniques and a step-by-step description of a systematic pedestrian safety program. The manual is intended to assist localities in establishing programs for planning, implementing, and evaluating pedestrian safety improvements.

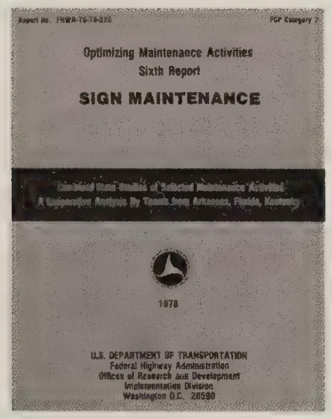
A six-step process for a pedestrian safety program is identified in the manual—Step 1: Determine the extent of the pedestrian safety problem; Step 2: Identify alternative solutions; Step 3: Select the best alternatives (benefit-cost analysis); Step 4: Implement selected alternatives; Step 5: Evaluate the effectiveness of the implemented alternatives; and Step 6: Maintain the pedestrian safety program. Each step is discussed in detail. In addition, several appendixes provide more detailed technical data and a glossary of terms used in the text.

Limited copies of the manual are available from the Implementation Division.

Optimizing Maintenance Activities, Sixth Report, Sign Maintenance, Report No. FHWA-TS-78-223

by FHWA Implementation Division

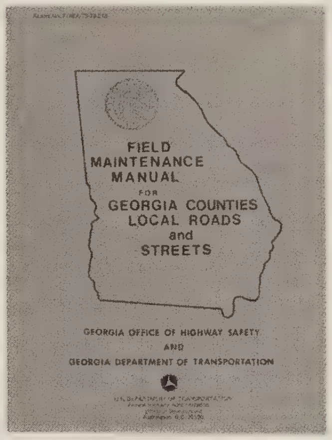
This report, the sixth in a special series on highway maintenance, summarizes the results of a sign maintenance value engineering study in Arkansas, Florida, and Kentucky. Included in the report are recommendations in the areas of proliferation of signs, traffic sign supports, centralized versus decentralized sign shops, and equipment and procedures. Purchasing procedures and sign lighting are also discussed, as is the use of a thin overlay to repair damaged signs.



Implementation of the study results will have different effects in each of the three study States depending upon current maintenance practices. Modifying existing procedures should result in substantial cost savings.

Limited copies of the report are available from the Implementation Division.

Field Maintenance Manual for Georgia Counties' Local Roads and Streets, Report No. FHWA-TS-79-218



by FHWA Implementation Division

This manual was prepared to assist maintenance personnel in Georgia county highway departments in identifying maintenance problems, causes of these problems, and corrective measures. Inventories of deficiencies and available equipment and personnel were taken in several Georgia counties. Specific areas studied include pavement, shoulder, drainage, bridge structure, and grounds maintenance.

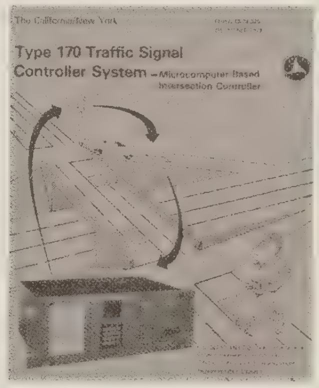
Although limited to highway maintenance problems in Georgia, the manual and corrective measures identified have nationwide application. The manual should be of interest to materials, maintenance, and pavement design engineers, and particularly maintenance personnel from State, city, and county highway agencies.

Limited copies of the manual are available from the Implementation Division.

Type 170 Traffic Signal Controller System—Microcomputer Based Intersection Controller, Report No. FHWA-TS-78-228

by FHWA Implementation Division

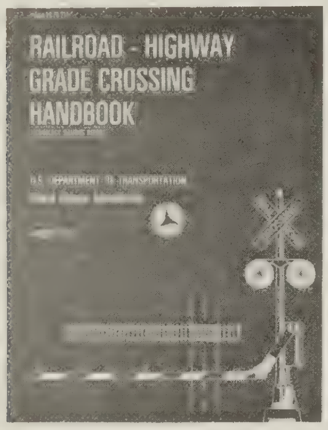
Traffic demands at some urban diamond interchanges have grown at increasing rates. This growth has increased traffic on the ramps of the diamond and the adjacent street system and caused a low level of service during rush periods. Considerable work has been done on real-time control of diamond interchanges in an attempt to optimize traffic flow throughout the interchange and retain smooth flow on adjacent corridors.



This report compares the 170 microcomputer-based controller to the minicomputer equipment and the hardwired equipment for diamond interchange control to show the flexibility and low cost of the controller. User orientation of the controller is explained and software considerations, such as man/machine interface, are described. The report concludes with a recommendation that the 170 controller be considered as a standard controller for all traffic signal control systems. The recommendations apply to most signalized intersections and ramps.

Limited copies of the report are available from the Implementation Division.

Railroad-Highway Grade Crossing Handbook, Report No. FHWA-TS-78-214



by FHWA Implementation Division

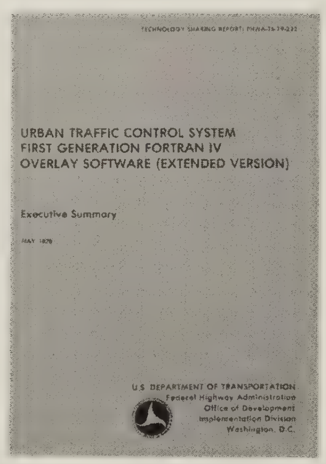
This handbook is a summary of applicable concepts, technology, and practice for railroad-highway grade crossings and provides information on improving the safety and efficiency of these crossings. The basic components of grade crossings are described by reporting on existing grade crossing technology. The handbook describes conditions and requirements at crossings, presents elements of crossing systems, reports on improvements to railroad-highway grade crossings, and aids in the application and understanding of new technology.

The handbook is available for $4.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-005-00027-5).

Urban Traffic Control System First Generation FORTRAN IV Overlay Software (Extended Version), Executive Summary, Report No. FHWA-TS-79-222

by FHWA Implementation Division

This report describes the control software developed in Charlotte, N.C., for FHWA. The software is used in traffic signal systems that are controlled by a digital computer. The software has been successfully operating for over 1 year and has been specified for several other control systems across the Nation.



This software package replaces earlier releases of the first generation software and contains more functional capabilities and features to reduce time and costs in implementing and operating the software in a typical computerized traffic control system.

Limited copies of the report are available from the Implementation Division.

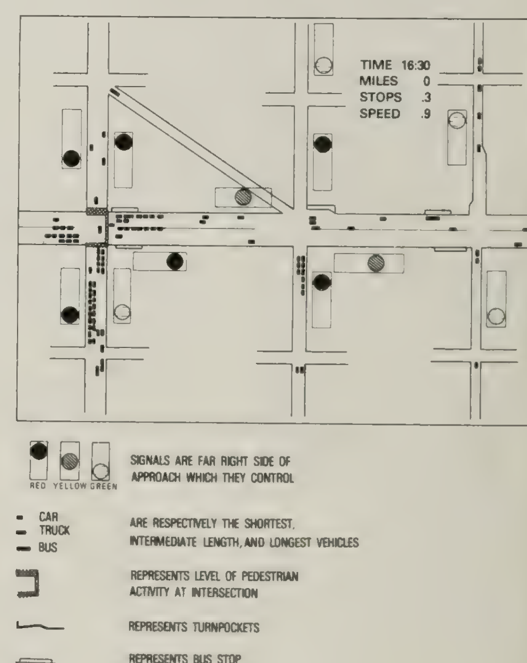
NETSIM

by FHWA Implementation Division

Traffic engineers have long needed an aid for evaluating the costs and benefits of alternative traffic control methods. Computer simulation modeling enables the engineer to inexpensively select the best alternative before funding its implementation. The Network Simulation Model (NETSIM) was developed by FHWA to fill the traffic engineer's need and has been used successfully throughout the United States in the last few years.

This 16 mm color/sound film demonstrates the capabilities of the NETSIM model and shows that traffic simulation can reliably predict the effects of transportation engineering changes on traffic flow in an urban street network.

The movie is available on loan from the National Highway Institute.



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 IV: Roadside Safety Hardware for Nonfreeway Facilities

Title: Multiple Service Level Highway Bridge Railings—Selection Procedures. (FCP No. 51V2113)
Objective: Develop bridge railing systems for a number of service levels. Determine the number of service levels needed based on the total costs of these railing systems. Refine multiple service level approach procedures accordingly. Develop an upgrading strategy. Assess the legal implications. Prepare a users manual.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78284
Expected Completion Date: December 1980
Estimated Cost: $200,000 (NCHRP)

FCP Project 1W: Skid Resistance Inventory Procedures and Equipment

Title: Pavement Surface Texture—Significance and Measurement. (FCP No. 31W2022)
Objective: Develop, evaluate, and demonstrate measurement methods for pavement surface texture and demonstrate effects of texture on skid resistance and on skid resistance-speed gradients. Establish secondary effects of texture and their significance. Develop empirical relationships between pavement texture and specific variables.
Performing Organization: Pennsylvania State University, University Park, Pa. 16802
Expected Completion Date: April 1982
Estimated Cost: $244,000 (FHWA Administrative Contract)

Title: Deployment of a Digital Road Profilometer. (FCP No. 41W3112)
Objective: Prepare specifications for profilometer. Adapt software. Make procedural changes. Continue to provide road surface measurements.
Performing Organization: University of Texas, Austin, Tex. 78701
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1981
Estimated Cost: $170,000 (HP&R)

FCP Project 1Y: Traffic Management in Construction and Maintenance Zones

Title: Determination of Driver Needs in Work Zones. (FCP No. 31Y1052)
Objective: Analyze driver tasks associated with approaching and traversing work zones. Determine and establish priorities for types of information needed by driver and how to convey information to driver. Determine needs for improvement of present system of traffic control devices.
Performing Organization: Institute for Research, State College, Pa. 16801
Expected Completion Date: December 1980
Estimated Cost: $311,000 (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: IMIS Phase 3—Development of Detailed Design and PS&E. (FCP No. 32C3042)
Objective: Design integrated motorist information system (IMIS) to be demonstrated on Northern Long Island Corridor. Include traffic surveillance, radar metering, incident management, route diversion, arterial signal control, and motorist aid in emergencies.
Performing Organization: Sperry Systems Management Division, Great Neck, N.Y. 11020
Expected Completion Date: August 1981
Estimated Cost: $2,348,000 (FHWA Administrative Contract)

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

FCP Project 3E: Reduction of Environmental Hazards to Water Resources Due to the Highway System

Title: Efficiency of Erosion Control Practices. (FCP No. 43E2224)
Objective: Evaluate the effectiveness of current erosion and sediment control practices. Determine optimum levels of erosion and

sediment control using design, construction, and maintenance of control procedures.
Performing Organization: Virginia Highway Research Council, Charlottesville, Va. 22903
Funding Agency: Virginia Department of Highways and Transportation
Expected Completion Date: June 1981
Estimated Cost: $161,000 (HP&R)

Title: Assimilative Capabilities of Highway Storm Water Runoff Retention Ponds. (FCP No. 43E3332)
Objective: Evaluate a retention basin based upon the first 25.4 mm (1 in) of highway storm water runoff. Determine its effectiveness as a mitigation measure. Determine reduction in pollutants, effects to ground water, and uptake by in-basin vegetation.
Performing Organization: U.S. Geological Survey, Orlando, Fla. 32800
Funding Agency: Florida Department of Transportation
Expected Completion Date: June 1982
Estimated Cost: $260,000 (HP&R)

FCP Project 3F: Pollution Reduction and Environmental Enhancement

Title: Evaluation of Highway Air Pollution Dispersion Models. (FCP No. 53F3502)
Objective: Develop methodology for evaluating highway dispersion model performance. Document a composite highway aerometric data base. Perform evaluation of selected line source dispersion models using above methodology and data.
Performing Organization: Stanford Research Institute International, Menlo Park, Calif. 94025
Expected Completion Date: June 1981
Estimated Cost: $200,000 (NCHRP)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4G: Substitute and Improved Materials to Effect Materials and Energy Conservation in Highways

Title: Evaluation of Sulfur-Asphalt Paving Mixtures in Ohio. (FCP No. 44G1302)
Objective: Conduct laboratory and field performance evaluation of sulfur-asphalt paving mixtures related to experimental construction projects in Ohio.
Performing Organization: Ohio State University, Columbus, Ohio 43216
Funding Agency: Ohio Department of Transportation
Expected Completion Date: March 1982
Estimated Cost: $146,000 (HP&R)

FCP Project 4K: Cost Effective Rigid Concrete Construction and Rehabilitation in Adverse Environments

Title: Use of Improved Structural Materials in Marine Piling. (FCP No. 34K3073)
Objective: Evaluate and compare the commercial manufacture, handling, driving, and field performance of marine piling made from polymer concrete, polymer-impregnated concrete, internally sealed concrete, latex-modified concrete, and concrete containing epoxy-coated rebars. Install the piles in a marine environment and compare with conventional prestressed concrete piles.
Performing Organization: Oregon Department of Transportation, Salem, Oreg. 97310
Expected Completion Date: October 1982
Estimated Cost: $149,000 (FHWA Administrative Contract)

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

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

Title: Wind Instrumentation of Mississippi River Bridge (Luling, La.). (FCP No. 45A1112)
Objective: Evaluate wind induced vibrations of the stays, vortex induced motion of the bridge deck, and wind climate and response of the bridge under extreme wind conditions.
Performing Organization: Tulane University, New Orleans, La. 70118
Funding Agency: Louisiana Department of Transportation and Development
Expected Completion Date: October 1981
Estimated Cost: $207,000 (HP&R)

FCP Project 5B: Tunneling Technology for Future Highways

Title: Improved Structural Design for Frozen Support Systems. (FCP No. 35B1432)
Objective: Develop improved structural design criteria and guidelines for frozen ground support systems. Review and evaluate current structural design technology. Determine where improvements can be made. Conduct experimental testing programs. Develop improved design criteria and structural concepts and write comprehensive guidelines for support systems.

*U.S. Government Printing Office: 1979—620-103/1

Performing Organization: Law Engineering Testing, McLean, Va. 22101
Expected Completion Date: September 1980
Estimated Cost: $127,000 (FHWA Administrative Contract)

FCP Project 5D: Structural Rehabilitation of Pavement Systems

Title: An Integrated Pavement Data Management and Feedback System (PAMS). (FCP No. 45D1322)
Objective: Determine the feasibility of developing a pavement data management system to develop this system.
Performing Organization: Louisiana Department of Transportation and Development, Baton Rouge, La. 70804
Expected Completion Date: December 1982
Estimated Cost: $162,000 (HP&R)

Title: Evaluation of Fabric Underseals. (FCP No. 45D2602)
Objective: Evaluate the performance of fabrics to establish realistic specification limits. Determine the types of distress, if any, that fabrics can economically correct.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843.
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: June 1983
Estimated Cost: $190,000 (HP&R)

Title: Performance, Reliability, and Durability of State of the Art Weigh-In-Motion Systems for Highway Vehicles. (FCP No. 45D3214)
Objective: Evaluate system performance, reliability, and durability of present state of the art weigh-in-motion bridges and systems for acquisition of highway statistical traffic data (phase A) and for truck overweight screening (phase 3).
Performing Organization: California Department of Transportation, Sacramento, Calif. 95814
Expected Completion Date: June 1981
Estimated Cost: $208,000 (HP&R)

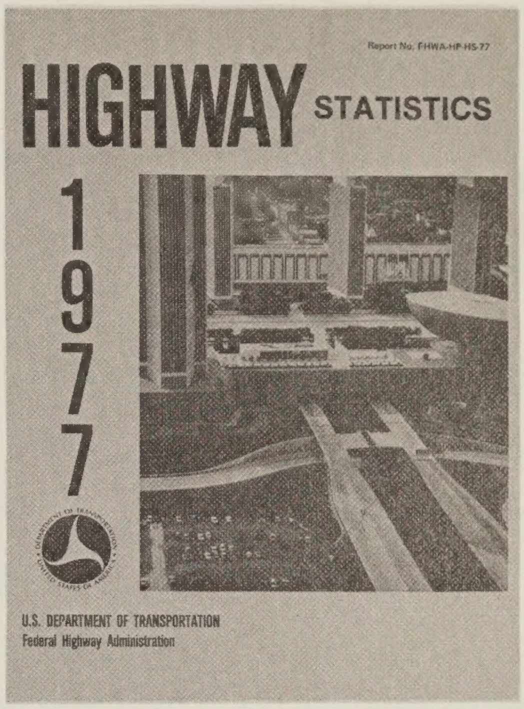
FCP Project 5J: Rigid Pavement Systems Design

Title: Mechanistic Design of Rigid Pavements. (FCP No. 35J2012)
Objective: Develop a new, practical, and implemental procedure for the structural design of rigid pavements (except prestressed concrete). Include tasks on literature and design methodology review, identification of distress mechanisms, development of mathematical models and computer programs, and field verification.
Performing Organization: Resource International, Worthington, Ohio 43085
Expected Completion Date: April 1982
Estimated Cost: $245,000 (FHWA Administrative Contract)

FCP Project 5L: Safe Life Design for Bridges

Title: Fatigue Testing of Weathered A588 Beams. (FCP No. 45L1082)
Objective: Determine the fatigue behavior of full size beams fabricated from A588 structural steel with a rust coat corresponding to 3 years of weather exposure. Obtain some 7-year weathering of small-scale tensile specimens.
Performing Organization: University of Maryland, College Park, Md. 20742
Funding Agency: Maryland State Highway Administration
Expected Completion Date: August 1984
Estimated Cost: $144,000 (HP&R)

New Publication



Highway Statistics, 1977, the 33rd publication in the annual series, presents statistical and analytical tables of general interest on motor fuel, motor vehicles, driver licensing, highway-user taxation, State and local highway financing, road and street mileage, and Federal-aid for highways. Also reported are 1976 highway finance data for municipalities, counties, townships, and other units of local government. A listing of the data is given in the table of contents and a brief discussion is given in the text accompanying each section.

The publication may be purchased for $5.25 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 00142-0). It is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 for $5.25 (Report No. FHWA-HP-HS-77) and in microfiche copy for $3 (PB No. 296097).

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The Evaluation of a Noncontact Profiling System Using the Acoustic Probe

Laboratory Studies of Lane Occupancy Signs

public roads

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