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COVER: The William Preston Lane, Sr., Memorial Bridge spanning the Chesapeake Bay in Maryland. The original span of the bridge was opened on July 30, 1952; the parallel span (under construction in the photograph) was opened on June 28, 1973.

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The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department.

Bridge Design, Maintenance, and Management

by
Charles F. Galambos

Introduction

The traveling public expects bridges—a vital segment of the U.S. surface transportation system—to be unfailingly safe and durable. In fact, it is a major news story if a bridge collapses or becomes unserviceable for some reason. Yet, it is reasonable to expect that in an aging transportation system the effects of traffic, accidents, and adverse environments would dictate a rate of component replacement that would ensure a certain level of expected service. However, when considering the need for replacing bridges, it is important to realize that some bridges were not designed to accommodate today's heavier and larger vehicles. In many cases, bridges can be strengthened and upgraded to serve for a few more years; in other cases, strengthening the bridge is not economical, so the bridge is replaced. The decision as to whether to strengthen or replace a bridge is made by the owners based on "engineering judgment." Inputs to that judgment include the present economic climate, the experience of the judge, and politics. Because of the widespread deficiencies in many of the Nation's highway bridges, and because the needs are greater than the available financing for upgrading or replacement, many owners are beginning to formalize a bridge management scheme. These efforts consider present and future availability of finances, the importance of a bridge, the public safety implications, maintenance needs, and any other relevant, quantifiable factors. This article discusses bridge management from a national viewpoint.

As technology advances producing newer and more durable materials for new construction as well as for bridge maintenance, the bridge design process also changes. As new specifications for loads and the resistance to withstand the loads are implemented, computer-aided designs expand the possibilities for making choices, and the storehouse of design input data becomes more statistically quantified. This article also discusses this phenomenon and its implications to the overall concept of bridge management.

Existing Bridge Stock

A good place to start thinking about bridge management is to examine the existing bridge stock or inventory. According to the latest Federal Highway Administration (FHWA) figures, there are 574,729 bridges on all highway systems in the United States—269,781 on the Federal-aid system and 304,948 on the non-Federal-aid system. About 49 percent of these bridges are constructed of concrete or prestressed concrete, 39 percent steel, and 12 percent are made of other materials, mostly timber. (*1*)[1] Figure 1 graphically shows the number of bridges constructed by decade since before 1900 to the 1970's. (*2*) This figure shows that approximately 200,000 of the existing bridges were constructed before or during the 1930's. Given the usually assumed lifespan of 50 years, well over one-third of the Nation's bridges should be replaced! But of

[1]Italic numbers in parentheses identify references on page 115.

course, age alone is no reason to replace a bridge; a deficiency must make the bridge unsafe or unfit for service.

Bridge Deficiencies

Much has been said in recent years about the many "deficient" bridges that exist on our various highway systems. Figure 2 presents one breakdown of these deficiencies by road system. (*1*) Note that more than twice as many bridges are rated deficient on the non-Federal-aid road system as on the Federal-aid system. "Deficient" bridges are not *unsafe* bridges. If a bridge is termed unsafe, it must be closed to the public. The bridge deficiencies fall into two larger groupings—those that are functionally obsolete and those that are structurally deficient.

An interesting breakdown of deficiencies is shown in figure 3, where the deficiencies are keyed to items in the "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges." (*2*) The guide outlines a condition rating, coded as a number from 9 to 0, for the various portions of a bridge. For example, a new condition is rated 9, and a poor condition needing immediate repair is rated 3. The rating of the condition of a bridge deck is especially detailed. Other guidance is provided for the condition rating of the superstructure, substructure, and the channel or channel protection for bridges over waterways. Some guidance for estimating the remaining life of a structure also is provided.

Figure 3 shows that for the structurally deficient bridges on the Federal-aid system, the deck condition accounts for the largest number of deficient bridges, whereas on the non-Federal-aid system, the overall structural condition accounts by far for the greatest number of deficiencies. For the functionally obsolete bridges, the deck geometry is the dominant cause of deficiency on both road systems.

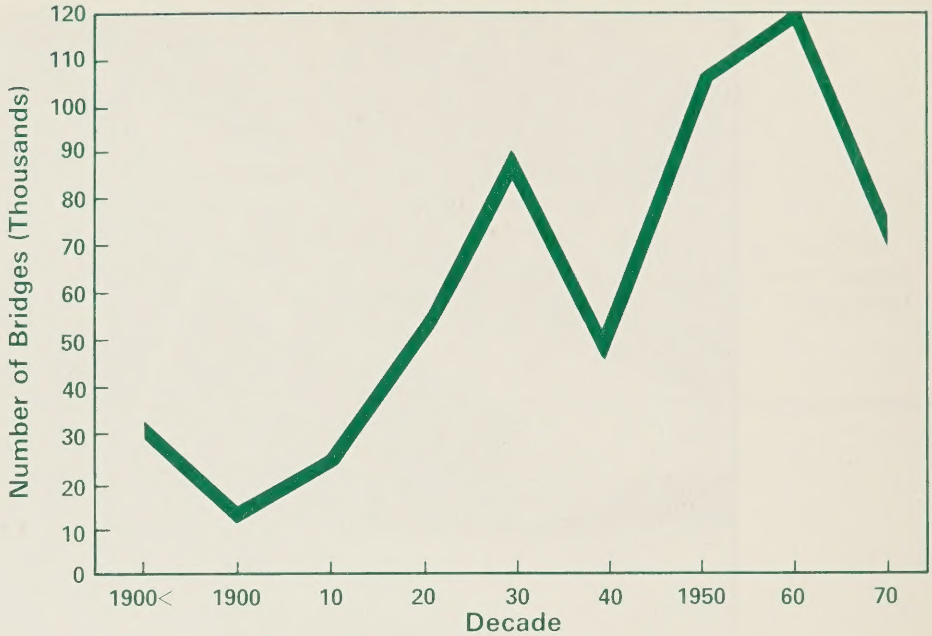

Figure 1.—Number of bridges constructed by decade.

	Federal-aid system	Non-Federal-aid system
Structurally deficient	33,400	107,400
Functionally obsolete	41,800	77,600
Posted	29,400	118,400
Closed	650	3,850

Figure 2.—Deficient bridges by road system.

The National Bridge Inventory, established by Congress (*3*) following the catastrophic collapse of the Silver Bridge at Point Pleasant, West Virginia, in 1967, presents an assessment of the condition of the Nation's bridges, giving some data and justification for the solicitation of funding for bridge replacement and rehabilitation. However, the inventory cannot contain all of the details useful to bridge maintenance engineers and designers. For example, from the inventory one can learn how many steel through-trusses there are and how old they are but not whether the trusses contain eyebars. Nor could one learn what the cause of a structural deficiency might be. For such information one must go to the owner of the bridge and look at the actual inspection report.

FHWA is required to report to Congress annually on the status of the highway bridge replacement and rehabilitation program. For this purpose, the National Bridge Inventory is very useful. The total number of bridges does not change markedly year after year, remaining near 575,000, but there were about 7,000 new bridges under construction in the last reporting period, and almost 11,000 bridges were improved. (*1*) This rate of new construction and bridge improvement is expected to continue.

	Structurally deficient						
	Deck condition	Superstructure	Substructure	Culvert	Overall condition	Waterway	Multiple deficiencies
Federal-aid system	5,950	3,260	4,750	420	2,900	510	15,610
Non-Federal-aid system	4,620	8,890	9,460	540	25,540	1,520	56,850

	Functionally obsolete					
	Structurally inadequate	Deck geometry	Clearance	Waterway	Approach	Multiple deficiencies
Federal-aid system	3,720	25,660	3,145	850	1,750	6,680
Non-Federal-aid system	7,090	44,930	900	1,420	2,810	20,410

Figure 3.—Structurally deficient and functionally obsolete bridges by road system.

Bridge Economics

In the United States, the general practice, often mandated by legislation, is that owners such as the State highway departments call for bids for the construction of a bridge for which the design and construction plans may have been prepared by others. The lowest responsible bidder then is selected. This process places extreme emphasis on the present cost and often does not take into account variations in maintenance expenditures during the life of the structure.

In recent years alternate designs have been required at the construction bid stage. However, the bid selection still is based on the lowest present construction cost, and no allowance is made for future maintenance expenditures.

Political and social forces are always also at work, influencing the kind of structures that are built in a given locality. Availability of local labor and materials, the experience of contractors, and the history of bridge building often overshadow pure engineering economics. For example, in California concrete bridges outnumber steel bridges by far; whereas, in the New England States and generally in the east coast States there are more steel bridges. Tables 1 and 2 list the predominant materials from which bridges are constructed according to State.

Bridge costs in 1985 based on bid prices for new construction range from $30 per square foot of deck area to well over $100 per square foot, depending on the complexity of the bridge and the combination of factors cited above. (*4*) In recent years, there have been more reinforced and prestressed concrete bridges constructed.

The need to upgrade and replace bridges will continue for some years because it is not possible to eliminate the large backlog of deficient bridges in a short time. Figure 4 shows an estimate of the costs to replace or rehabilitate the existing deficient bridges, arranged according to highway system. Funds needed are just under $50 billion. The fiscal year 1986 funding authorization by Congress for the several rehabilitation and replacement programs was $1.90 billion. Other highway funds obligated for bridge work increase the total to over

	Sufficiency rating <50 (Number of bridges)	Cost (Billions of dollars)	Sufficiency rating 50-80 (Number of bridges)	Cost (billions of dollars)	Total cost (billions of dollars)
Federal-aid system	26,850	16.1	35,990	11.2	27.3
Non-Federal-aid system	120,160	17.2	53,020	3.8	21.0
Total	147,010	33.3	89,010	15.0	48.3

Figure 4.—Cost to replace or rehabilitate bridges by road system.

$2 billion—still very short of the needed funding. Therefore, it continues to be necesssary at all levels of government to raise additional revenue for bridge programs. As seen in figure 4, the problem is especially acute in jurisdictions having many non-Federal-aid bridges. Some concession to this problem was made in the 1982 Surface Transportation Assistance Act in that the States must spend no less than 15 percent of each year's apportionment on the non-Federal-aid system bridges and they can spend up to 35 percent. Approximately 20 percent of the apportionment actually is spent on non-Federal-aid system bridges.

Bridge replacement funds are likely to continue to be appropriated by Congress as well as come from increased State taxes. However, the owners of non-Federal-aid system bridges also need assistance. Possibly it would be appropriate to use another set of rules for the rating of non-Federal-aid system bridges, accepting some lower level of service, but assuring that the safety of the traveling public is not compromised. This is, however, a controversial political and social issue.

A rule of thumb for maintenance of an acceptable level of service when the bridge stock is mature (no more new highway systems are being added) is that 2 percent of the replacement value of the entire stock must be spent annually for bridge maintenance, rehabilitation, and replacement. (*5*) For the 575,000 highway bridges in the United States, this would amount to about $3 billion a year. Again, it would cost almost $50 billion to replace or rehabilitate the existing deficient bridges, as pointed out in figure 4.

Table 1.—Number of bridges according to materials—Federal-aid system

State	Concrete	Steel	Timber	Other
Alabama	5,227	1,728	608	58
Alaska	179	315	72	0
Arizona	3,947	468	23	1
Arkansas	3,556	1,931	366	4
California	12,953	1,493	278	36
Colorado	1,976	1,102	369	26
Connecticut	919	1,634	7	53
Delaware	176	272	11	10
Dist. of Col.	72	142	0	1
Florida	5,093	832	42	10
Georgia	4,719	3,163	38	17
Hawaii	581	75	13	0
Idaho	1,350	236	83	0
Illinois	6,101	4,381	18	23
Indiana	4,283	2,820	26	29
Iowa	4,010	3,001	92	15
Kansas	7,989	2,418	223	70
Kentucky	4,034	860	5	15
Louisiana	4,254	637	714	64
Maine	503	735	6	5
Maryland	901	1,524	41	19
Massachusetts	1,000	2,443	74	142
Michigan	2,088	3,673	56	17
Minnesota	2,741	1,908	399	9
Mississippi	4,902	1,746	892	2
Missouri	4,881	3,777	32	9
Montana	1,207	443	913	1
Nebraska	2,869	2,000	230	5
Nevada	697	86	7	0
New Hampshire	453	746	15	16
New Jersey	1,255	2,785	60	51
New Mexico	2,314	358	176	2
New York	2,500	6,179	26	104
North Carolina	2,614	2,588	213	3
North Dakota	1,114	502	71	0
Ohio	5,604	6,429	23	94
Oklahoma	4,973	2,753	154	165
Oregon	2,705	594	436	2
Pennsylvania	7,044	3,657	7	202
Rhode Island	220	317	13	12
South Carolina	3,346	802	66	3
South Dakota	1,772	876	109	1
Tennessee	5,897	1,190	178	10
Texas	22,136	3,095	76	55
Utah	1,042	425	23	6
Vermont	405	875	5	6
Virginia	3,425	3,384	18	18
Washington	3,143	465	295	37
West Virginia	1,389	1,940	3	64
Wisconsin	3,271	2,931	82	9
Wyoming	1,102	689	116	1
Puerto Rico	680	201	0	5
Total	171,612	89,624	7,803	1,507

Bridge Maintenance

Several levels of bridge maintenance are practiced, depending on the complexity and frequency of the tasks involved. These tasks range from the clearing of drainpipes to the replacement of bearings. Common, relatively routine maintenance consists of cleaning the drainage system, patch painting, removing debris, tightening obviously loose bolts, and cleaning the joints.

The next level of maintenance includes adjusting bearings, complete repainting, repairing potholes, filling cracks, and sealing concrete.

The third level of maintenance activities approach rehabilitation in that they might include the replacement of bearings; readjustment of forces, such as in cables; replacement of joints; fatigue crack repair; waterway adjustment; and other specialized activities not performed very often.

It is difficult to obtain accurate cost figures for bridge maintenance activities; the expenditures are likely to be lumped with general road maintenance, which includes such activities as snow removal and grass cutting. Often, it is only certain that maintenance personnel spent time somewhere on the highway system. Much of the cost of maintenance should be ascribed to the handling of the traffic during maintenance activities. Annual estimates of bridge maintenance costs range from $200 per bridge on up.

Fundamental to the intelligent expenditure of maintenance funds is a knowledge of how long a bridge component will last. (*6*) That variable is greatly affected by construction quality, materials quality, the bridge environment, and the kind and amount of bridge traffic. For example, a properly applied inorganic zinc-rich primer, an epoxy intermediate coat, and a methane top coat in a moderate climate may last as long as 20 years. A lesser quality three-coat oil-alloyed paint system may last only 2 years in a severe climate.

Table 2.—Number of bridges according to material—Non-Federal-aid system

State	Concrete	Steel	Timber	Other
Alabama	3,321	1,761	2,492	167
Alaska	17	81	138	0
Arizona	571	173	81	0
Arkansas	2,198	2,060	2,837	6
California	5,018	1,472	956	25
Colorado	924	1,814	979	44
Connecticut	441	650	30	24
Delaware	89	109	44	20
Dist. of Col.	11	10	0	0
Florida	2,900	383	778	10
Georgia	2,687	2,506	1,069	54
Hawaii	295	26	42	5
Idaho	1,178	517	352	0
Illinois	8,306	6,135	228	31
Indiana	5,135	4,899	265	146
Iowa	4,871	9,082	4,850	75
Kansas	5,896	6,347	2,572	204
Kentucky	4,354	2,916	293	50
Louisiana	2,864	464	4,996	26
Maine	405	859	62	15
Maryland	565	1,036	199	41
Massachusetts	328	735	79	65
Michigan	1,233	3,087	369	34
Minnesota	2,866	3,384	1,603	24
Mississippi	3,716	1,289	4,458	18
Missouri	3,351	10,902	662	21
Montana	486	927	891	5
Nebraska	1,053	6,648	3,219	6
Nevada	137	69	45	1
New Hampshire	309	860	133	27
New Jersey	431	1,011	228	39
New Mexico	264	129	189	15
New York	1,364	6,665	229	319
North Carolina	1,957	6,824	1,774	13
North Dakota	861	1,743	1,063	0
Ohio	5,488	10,940	195	201
Oklahoma	4,169	6,689	3,442	583
Oregon	1,432	506	900	0
Pennsylvania	5,421	5,287	325	374
Rhode Island	47	66	16	7
South Carolina	3,359	669	646	7
South Dakota	1,247	2,165	862	20
Tennessee	6,513	3,153	1,342	15
Texas	8,257	4,753	4,942	204
Utah	457	315	194	1
Vermont	312	966	84	6
Virginia	1,521	4,072	82	3
Washington	1,606	430	776	19
West Virginia	883	2,177	76	116
Wisconsin	2,405	3,733	411	44
Wyoming	218	427	277	2
Puerto Rico	618	164	0	8
Total	114,349	134,085	52,775	3,169

The basic materials of bridge components—steel, concrete, and timber—are likely to have differing maintenance needs. Steel surfaces usually need corrosion protection, and steel bridges are subject to fatigue damage. Concrete suffers from freeze-thaw damage, may develop cracks from lack of tensile strength, and is subject to internal damage created by the expansion of corrosion products because of the penetration of chloride ions to the reinforcing steel. Timber is subject to dry rotting and attack from organisms.

As with many items constructed by humans, bridges require more maintenance as they age. As discussed earlier, many bridges are older than 50 years, which accounts for the enormous maintenance burden that presently exists. Because of this, many highway departments are seriously considering a more formal approach to bridge management.[2]

Bridge Management

In its largest context, bridge management encompasses all of the elements of planning, inspection, load rating, maintenance, rehabilitation, replacement financing, and record-keeping that are required to maintain a specific level of service. (*7*) The management could encompass all of the bridges in a jurisdiction or highway system or it could be applied to only a single bridge. The level of service likely would be defined by traffic speed and load capacity as well as some acceptable time of service interruption.

It has been recognized for some time that a bridge inventory and bridge condition assessment are fundamental to the establishment of a management system. The National Bridge Inventory, along with the deficiency ratings, has served to highlight fiscal needs to Congress and served as input for the funding apportionments to the States. Several States have established more detailed deficiency rating schemes to help prioritize bridge replacements. The maintenance needs are as yet not as well quantified, but studies are continuing and maintenance management schemes are being implemented. Sound engineering answers are required to the questions of where, when, and for what purpose money must be spent to maintain the previously defined levels of service on bridges.

Another approach to establishing a bridge management system is by analyzing the causes of problems resulting from traffic and problems caused by the environment.

Traffic can cause fatigue cracks in some bridge elements and sometimes cause overloading problems. To determine potential fatigue crack repairs, it is necessary to inventory fatigue-prone details and match the details with an expected stress spectrum. Good progress is being made on the establishment of the stress spectra, but the inventorying of fatigue-prone details is, for the most part, yet to be done.

Overloads can cause irreversible damage to bridges, but outside of instituting very strict load enforcement measures, no safeguard exists for avoiding damage from overloads. In a similar sense, there will be accidental impacts on bridge components that must be repaired. Possibly, guidance must come from past records of overload and accident damage.

To a much smaller extent, traffic may cause bearings to readjust, especially on bridges with unidirectional traffic.

Environmentally-caused bridge maintenance costs are by far larger than those caused by traffic. Those States having many steel bridges, especially near the seacoast, spend a lot of money cleaning and repainting them. Repainting can be scheduled based on past performance, with judicious allowances being made for the longer-lasting newer paint systems.

One of the most damaging environments for bridges is created by applying deicing salts, which cause the internal reinforcement corrosion in concrete and the general corrosion of steel. Many studies have been made and are continuing on relating salt application to corrosion rates and developing methods for mitigating and even stopping the damage. Again, based on past experience and careful condition surveys, salt-damaged member repairs can be scheduled and costs estimated. The cost of inspection and damage assessment surveys also is an expense and should be planned for.

Bridges over waterways can be damaged by floods and ice flows. Cleaning debris, maintaining bank protection, and repairing scour damage are required. Occasionally, the waterway may have to be dredged or realigned in some way. Bridges over navigable waters and moveable bridges have their own special maintenance needs, including impact protective devices, lights, and the machinery required.

Bridges in some parts of the country suffer damage from earthquakes, and whereas much research on earthquake prediction is continuing, it is not possible to adequately plan for and manage earthquake damage. The maintenance of instrumentation for the monitoring of seismic activity, however, can be included in a management plan.

[2] "Cost-Effective Bridge Maintenance Strategies," Report Nos. FHWA/RD-86/109-110, Federal Highway Administration, Washington, DC. Not yet published.

From the above it can be seen that an all-encompassing bridge management scheme can very quickly become extremely complex and costly to establish. Furthermore, it could be a great waste of time and money if the information data base is incorrect or not maintained, or worse yet, the whole system is bypassed for the sake of political expediency.

From a national viewpoint, a uniform bridge management scheme administered by each State in the same manner could be beneficial. The benefits would relate mainly to the administration of bridge rehabilitation and replacement programs. However, as pointed out earlier, there are many important local influences that overshadow "average" or "uniform" bridge behavior.

Federal programs that involve the disbursement of funds are usually accompanied by a set of rules for the accounting of those funds. It is expected that if Congress should legislate funds for maintaining bridges, a formula for the disbursement of the funds would be developed that would require a substantiation of needs, which in turn should be based on factual expenditures for painting, crack repair, concrete patching, and any of the other many maintenance activities. Such substantiation on a national scale would then produce a more reliable basis for estimating how long the various components of a bridge last.

Summary and Conclusions

This article reviews the present state of the National Bridge Inventory, pointing out that there are many deficient bridges and that there is an enormous backlog of bridge rehabilitation and bridge replacement need amounting to nearly $50 billion. The concept of bridge management has been introduced with the desirability of having some uniformity in approach on a national scale, keeping in mind, however, that the burden of establishing and maintaining a record system be not greater than the value received.

In light of the trend toward load and resistance factor bridge design specifications based on a probabilistic approach (*8*), it is re-emphasized that most bridge maintenance expenditures correct problems caused by the environment, especially the application of deicing salts, which is controllable by bridge maintenance personnel. Acid rain, air pollution, salt spray from the ocean, and freeze-thaw cycles are not under the control of bridge maintenance personnel and whether some of these damaging forces will get better or worse in the future should be of serious concern to those formulating radical design specification changes.

When considering loads, it is to be emphasized that if the design live loads are too close to the allowable vehicles actually using the bridges, it becomes extremely important to enforce weight laws.

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(*7*) "Bridge Management," Seminar Documents, Demonstration Projects Program, *Federal Highway Administration,* Washington, DC, October 1986.

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Charles F. Galambos is Chief of the Structures Division, Office of Engineering and Highway Operations Research and Development, FHWA. He has been active in bridge research for over 25 years and is especially interested in bridge loadings and fatigue and fracture problems. Mr. Galambos continues to actively participate in national and international bridge committees concerned with bridge safety.

A Sign Management System to Maintain Sign Visibility at Night

by
Jeffrey F. Paniati, Douglas J. Mace, and Robert S. Hostetter

Introduction

The U.S. highway transportation system is a complex conglomeration of roadways, ranging from high-speed Interstate highways to busy urban arterials to rolling rural roadways. Although these roadways vary greatly in size, traffic volume, and operation, they do have one thing in common—traffic control signs. It is not uncommon for a single mile of urban freeway to contain 25 to 30 signs, and even the most rural of roadways has a surprisingly large number of signs.

Managing the installation and maintenance of signs on roadways is an increasingly difficult task. The advent of the microcomputer has led to the development of automated sign inventories and road logs. The introduction of innovative software is needed to provide more efficient and objective solutions to the problems of sign maintenance management. This software not only will improve sign maintenance management but also may improve public safety by implementing sign visibility standards in a practical and cost-effective manner. Statistics show that sign visibility standards for nighttime operation need improvement.

Nighttime fatalities are over-represented in accident statistics—approximately 60 percent of all fatalities occur at night. As shown in figure 1, the mileage fatality rate—the number of fatalities divided by the number of miles traveled—is three times higher at night than during the day. (*1*)[1] These higher rates can be attributed to many factors (for example, alcohol and fatigue), but traffic engineers agree that improving roadway guidance results in improved traffic operation. Signs must provide the necessary regulation, guidance, and warning to allow drivers to travel smoothly and safely toward their destinations.

It is extremely important that signs be installed and maintained correctly and effectively. A study of highway tort liability in Pennsylvania showed that signing deficiencies were cited as the primary factor in 20 percent of the sampled tort actions, second only to pavement deformities (22 percent). When considering only those highway accidents where a fatality or serious injury occurred, signing deficiencies rank as the primary factor most often cited (41 percent). (*2*)

[1]Italic numbers in parentheses identify references on page 123.

Between fiscal years 1979 and 1982, the States paid in excess of $84 million to settle highway tort claims. At the end of 1983, there were an additional 10,000 tort claims pending against the States. (*3*) The cost of tort liabilities is not limited to settlement payments, the State also incurs expenses for processing, investigating, and settling claims.

With the current trend in the courts toward increased liability and the award of large judgments and with skyrocketing insurance premiums, the need exists for proper sign installation and systematic replacement.

Unfortunately, sign installation and maintenance standards, especially for retroreflective signs for night visibility, are incomplete. The Manual on Uniform Traffic Control Devices (MUTCD), which sets forth the basic principles on sign design and use for all streets and highways open to public travel, currently requires that all warning, regulatory, and overhead guide signs be reflectorized or externally illuminated to show the same color and shape by day or night (unless specifically excepted in the standards) and that the legends and borders of other guide signs be reflectorized or the signs be internally illuminated. (*4*) The MUTCD, however, provides no minimum or replacement requirements for retroreflective signs. New signs, therefore, are installed with various retroreflectivity levels (depending on the material chosen), and sign replacement varies in and among States.

The severity of the problem is such that the Federal Highway Administration (FHWA) has initiated and is considering rulemaking on standards for retroreflective traffic control devices. (*5*) A study currently is underway to determine the retroreflective requirements for signs, markings, and other traffic control devices.

This article describes the framework for a sign maintenance system (SMS) being developed to assist State and local highway organizations involved in the design, management, maintenance, and research of retroreflective traffic signs. The system components are outlined, results of a preliminary evaluation are presented, and ongoing and future research efforts are discussed. Possible applications of the SMS as it now exists are described, and some conclusions are drawn as to what additional work is required for the system to become fully operational.

Sign Maintenance System

The SMS is a microcomputer-based system that can be accessed directly through interactive instruction or linked with an automated sign inventory. Using information from various models and data bases, the SMS can outline driver visibility requirements and the degree to which specific signs satisfy these requirements. Thus, the SMS not only develops a data base of signs, but uses that data base to predict candidate signs for replacement and to compare various replacement strategies and their costs.

The SMS is composed of a sight distance requirement model, an aging (sign deterioration) model, a required luminance model, and an available luminance model. For proper operation, the SMS requires three supporting data bases—a sign inventory, a sign dictionary, and a road file. Figure 2 illustrates the interaction of these data bases with the models and presents the overall structure of the SMS.

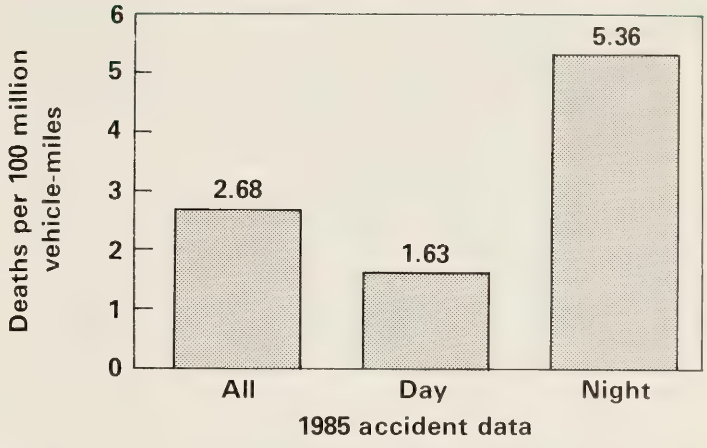

Figure 1.—Comparison of day/night mileage fatality rates.

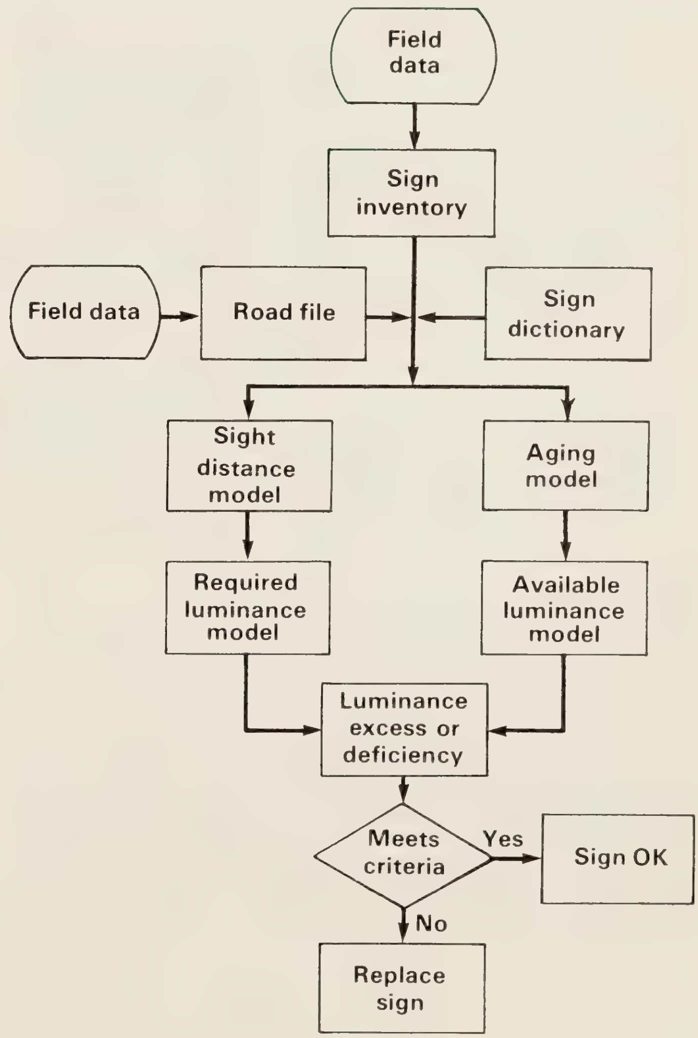

Figure 2.—Logic flow of the SMS.

It should be noted that in developing the SMS as it now exists, only data from previous research were used. As a result, there are gaps in knowledge that prevent the system from being fully operational at this time. The SMS framework was developed, however, to allow for easy modification as additional research is completed. Ongoing and planned FHWA research will fill these gaps and provide for a reliable and useful SMS in the next few years.

Sign inventory

The sign inventory is the primary data file that must be input by the user. It includes a roadway code, a sign code, and sign-specific information such as:

- Location, including the sign location along the road, the position (right, left, median, overhead), and the offset from the side of the road.
- Physical measurements, including the sign dimensions, the sign blank materials (aluminum, steel, wood), the sheeting type and manufacturer, and the existing reflectivity.
- Installation and last inspection dates.

The recommended action, such as cleaning, replacement, or relocation of the sign, also can be recorded.

Sign dictionary

The SMS includes a sign dictionary containing standard sign characteristics, such as colors, class, and message complexity, for nearly every sign in the MUTCD and the Standard Highway Signs booklet. (*6*) The user selects these standard characteristics by inputting a sign code, generally the MUTCD code. For example, if the code R1-1 (STOP sign) is entered, a dictionary record containing the sign legend, the legend type (message), the sign shape, the letter stroke width-to-height ratios, and a list of generally used sign sizes is recalled. The required driver action, sign criticality, maneuver location requirements, reading or recognition time requirements, decision complexity, and sign class also are stored for each sign (fig. 3). The use of a sign dictionary shortens the data entry time, reduces computer memory requirements, and minimizes the possibility of error.

Road file

The SMS also requires the user to input information on the kind of roadway operation (for example, one- or two-way traffic), number of lanes, lane width, and typical speed and volume for a given roadway section. This information is stored in the road file and referred to indirectly by including a roadway identifier in the sign inventory file. Although considerable data input is required initially, once these data are entered for a given road section, the data need only be updated periodically as changes to the road system are made or as new volume and speed data are collected.

Default values for sign placement and height are included in the road file, to be used if this information is not available in the sign inventory. The user also may enter characteristics unique to the given highway section. A sign deterioration factor can be input to indicate the relative rate at which signs age along that section—signs along a roadway serving an industrial plant might have a higher deterioration rate than do signs along a sparsely traveled shaded road. Visual complexity can be entered, ranging from low as on most rural roads to high as in a downtown location where illuminated advertising makes it more difficult to find a roadway sign.

Models

The three files described above comprise the data base in which the software operates. The four models in the software use data items from these files to compute the following:

- Specific intensity—the ratio of the light reaching a sign to the light reflected by the sign toward the source—per unit area (SIA).
- Available luminance—the light that is reflected from the sign toward the eye of the observer.
- Luminance deficiency—a comparison of specific intensity or available luminance with that required for legibility or detection.

Entry	Code	Meaning
Sign criticality	1	Stop required
	2	Other maneuver required (for example, lane change)
	3	Other regulatory sign (for example, speed limit)
	4	Other warning sign (for example, curve ahead)
	5	Guide sign
	6	Information only
Maneuver required	0	None
	1	Stop
	2	Lane charge
	3	Reduce speed
	4	Turn
	5	Yield
Maneuver location (if required)	0	After passing the sign
	1	Before passing or on reaching the sign
Reading time	—	Number of seconds needed to read the sign
Decision complexity	0	No decision required
	1	Simple decision
	2	Complex decision
Sign class	1	Maneuver required (for example, lane drop)
	2	Other response required (for example, TURN OFF 2-WAY RADIO)
	3	Decision only required (for example, exit in 2 miles)
	4	Recognition only required (for example, milepost)

Figure 3.—Illustrative sign dictionary codes.

These can be used as replacement criteria.

Although sufficient data were not available to build fully acceptable models, the best available knowledge was extracted from the literature and incorporated into these models. The logic flow within each model, and the interaction between the models is shown in figure 4. The four models, at varying levels of sophistication and development, are outlined below: (*7*)

Sight distance requirement model: Predicts the distances at which any sign should be detectable and legible. The validity of this model is being examined further under an FHWA 2-year research study.

Luminance requirement model: Determines the luminance level required to provide the needed sight distance for reading and reacting to any sign. Additional information on the required luminance levels is being obtained under an FHWA 2-year research study.

Aging model: Assesses deterioration of sign performance over time. A current FHWA 1-year research fellowship study is examining the deterioration of inservice signs to obtain additional data that can be used to further calibrate the model.

Available luminance model: Calculates the amount of luminance under varying conditions of sign location, placement, source illumination, and observer position. Additional information on available luminance is being obtained under an FHWA 2-year research study.

Using the SMS

The SMS application software ties together the data files and models to produce a list of signs recommended for replacement. The SMS identifies these signs based on one or more user-selected criteria, including age, reflectivity, and an estimate of the luminance excess or deficiency with regard to driver requirements.

Using a "what-if" procedure, the budgetary impact of different replacement schedules can be evaluated. For example, the following can be determined: The cost of replacing all signs over 12 years old, regulatory signs with reflectance below 50 SIA (cd/fc/ft²[cd/lx/m²]), or critical signs (those requiring a stop maneuver) whenever available luminance was less than 120 percent of the minimum luminance drivers require. Signs also can be selected for replacement based on a combination of values in the general categories of location and sign type. For instance, all STOP signs installed over 5 years ago on specific routes could be selected from the categories of location, age, and sign type.

Potential system users

At least three distinct kinds of users could benefit from access to the SMS: Managers, operations personnel, and researchers.

Managers: Managers may use the proposed SMS to evaluate the cost impact on sign maintenance budgets of

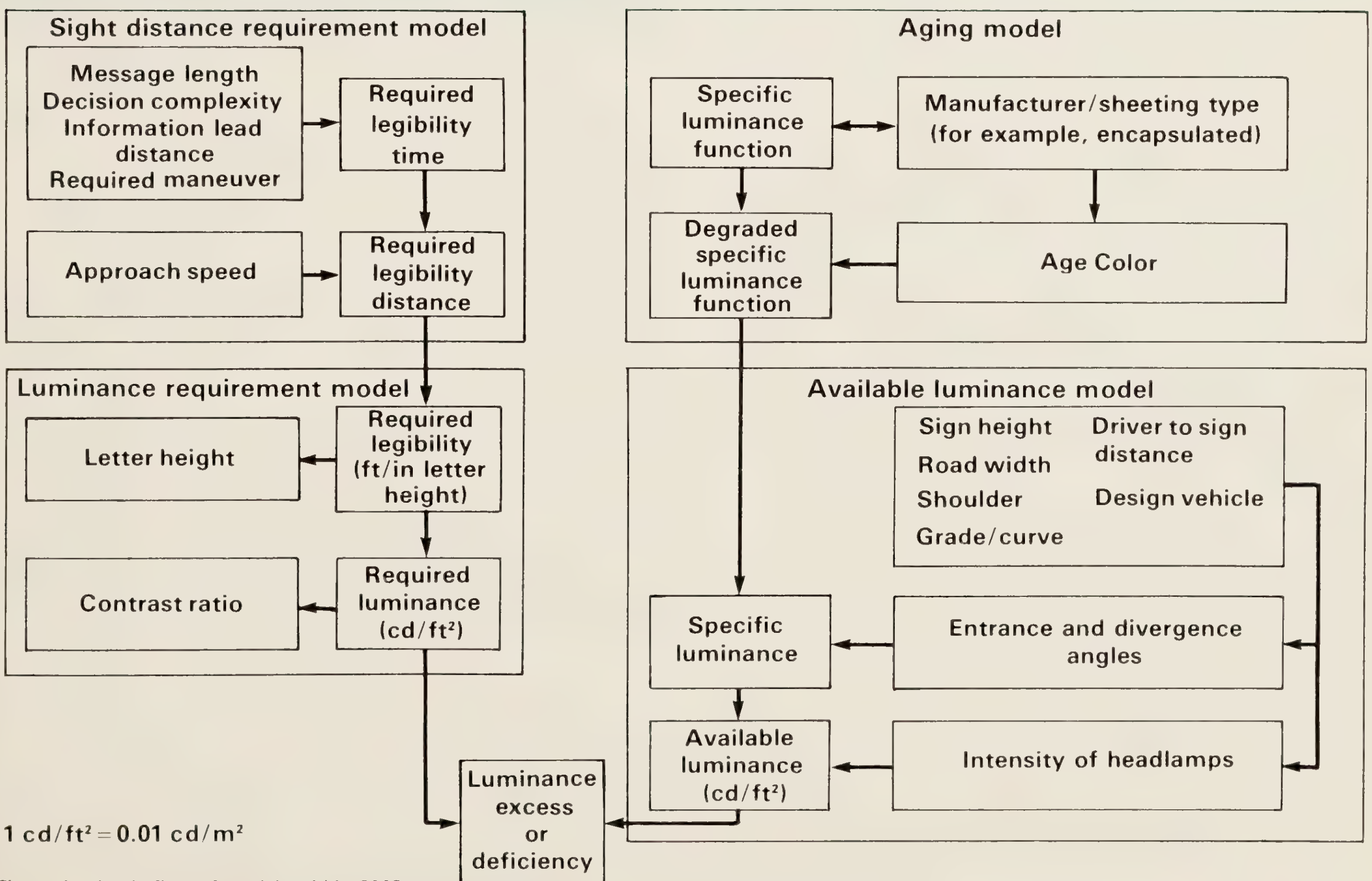

Figure 4.—Logic flow of models within SMS.

different sign replacement schedules or strategies. They may use SMS to forecast sign maintenance budget requirements by projecting different future sign inventories and to provide a systematic and efficient sign maintenance model for use in potential tort liability cases.

Operations: The SMS can assist in maintaining and evaluating signs by providing a list of signs that need replacing or require inspection according to any management decision. This list can be organized by sign type or location and can be made to interface with a system that generates work orders. The SMS can be updated continually by requiring work crews to supply the necessary sign inventory data for both new sign installations and sign replacements.

Researchers: Using the SMS interactively, researchers can explore alternative methods of satisfying driver needs. The SMS may help reduce driver requirements for luminance (for example, suggest symbol messages) or increase the luminance available (for example, change in headlight distribution or increased reflectivity). The SMS can be used to answer questions on the influence of different variables on driver requirements and sign luminance—how changes in road width, sign placement, or reflective materials would change the luminance available at the distance the driver must detect or read the sign. Or, a user might be interested in how changes in message length, sign size, or approach speed affect the required legibility distance and required luminance.

Application of the SMS

Although the SMS is not fully operational at this time, parts of the system have been tested and are available for use.

At its most basic level, the SMS can be used to develop and maintain a sign inventory. The SMS data bases provide a menu-driven computer system for compiling and indexing an inventory, a complete sign dictionary containing standard sign characteristics, and a road file to store pertinent roadway information. In this form, the SMS can be used to track the age and condition of signs and provide for a systematic review process.

Although a systematic review based on sign age is preferable to the random review process or reviews based on driver complaints (currently used by many jurisdictions), a systematic review still requires a subjective judgment of the sign quality and also requires that the signs be visually inspected under nighttime conditions. Daytime inspection does not identify all deficient signs that need to be replaced. The deterioration of the T-intersection sign in figure 5 is obvious; however, the crossroad sign appears adequate and not in need of replacement. When viewed under nighttime conditions, however, it was found that both signs were in poor condition and needed to be replaced.

Figure 5.—T-intersection sign and crossroad sign.

A system that would apply a decision rule based on a quantifiable measurement of each sign's retroreflective qualities is needed. Such a system was tested by conducting a field evaluation of the SMS as it now exists with a series of performance standards suggested by Sivak and Olson that provide different levels of SIA for different geometric situations as the criteria for sign replacement. (*8*) SIA can be obtained using a commercially available retroreflectometer. Because the retroreflectometer is equipped with its own calibrated light source, the retroreflectometer can be used under daylight conditions.

The reasonableness of the replacement levels suggested by Sivak and Olson and of alternative replacement levels using SIA were tested. In addition, criteria that reflect differences in sign criticality and sign type (alphanumeric versus symbol) were studied. (*7*)

Experimental procedure

The experimental procedure required that knowledgeable highway personnel drive a test route at night and evaluate signs to determine whether the signs should be replaced. This would determine if the decisions based on the replacement strategies were reasonable when compared with those decisions made by an "expert panel."

The subjects were told to drive a specific route and maintain a speed at or below the posted limit. They were to slow down or stop if necessary to maintain considerable lead distance. They also were to allow following vehicles to pass if the vehicles' lights might interfere with the driving task and the visibility of the sign.

Independent variables

The two major independent variables were sign criticality and sign reflectivity. Every sign in a computerized inventory was assigned a level of criticality as discussed earlier. To evaluate the procedure, two criticality classes were created: Signs with a criticality of 1 or 2 (those where some kind of maneuver would be necessary) and signs with criticality levels of 3 through 6. This second class of signs is less important in terms of legibility distance.

Test signs were selected to represent as wide a range of reflectivity as possible; the selection was made with regard to the amount of SIA. The levels of SIA ranged the replacement levels recommended by Sivak and Olson. (*8*)

To ensure the generalizability of the SMS to different inventories of signs, additional independent variables had to be sampled including sign placement, road type, and color/shape. Sign placement enables categorization by right shoulder, left shoulder, median, and overhead locations. Road type was varied by including two-lane rural and four-lane with and without median. Both bright and dark rural areas were included.

Black-on-yellow, black-on-white, and white-on-red signs were included in rectangular and diamond shapes to enable sampling a range of colors and shapes. The unique shapes of the no-passing pennant and STOP signs also were included.

Because so many variables had to be tested, a complete factorial design was not feasible. In fact, stratification on the variables of interest was difficult because of the constraint that all signs had to exist along a route that could be driven in 2 hours. The final test route contained 65 signs; 25 different signs were included ranging from high criticality signs (STOP) to low criticality signs (State route marker).

Dependent variables

The principal evaluation variable, whether to replace a sign, was obtained empirically from each subject for each sign and analytically from the SMS using alternative measures of luminance.

Subjects

Eight subjects provided the empirical data. Two subjects were Pennsylvania Department of Transportation traffic engineers whose normal activities involved judgments about sign placement and the evaluation of sign brightness. Three subjects were township managers with responsibility for sign replacement but without the training of traffic engineers. The final three subjects included a sales representative from a sheeting manufacturer and two people involved in highway research.

Equipment

The subjects drove a 1976 van equipped with calibrated halogen headlamps. Photometric grid values at 12.8 V were obtained for the headlamps before installation. To ensure that operating voltage would be uniform at 12.8 V, an auxiliary 6-V battery and a voltage regulator were installed in the headlamp circuit.

Replacement strategies

The field evaluation was conducted by comparing the sign replacements indicated by the six alternative replacement strategies with the recommendations of the expert panel (table 1).

The first strategy used the SIA values suggested by Sivak and Olson. (*8*) Strategies 2 and 3 represent a 75 percent and 50 percent reduction of these recommended values, respectively. Strategy 4 used the criticality as the criteria to determine which performance standard to use. The Sivak and Olson values are used for the more critical signs—criticality rating equal or less than 2—with a 50 percent reduction used for the less critical signs. Strategy 5 used sign type as the criteria. The Sivak and Olson recommendations are used for the alphanumeric signs, and 50 percent of the recommended values are used for symbol signs. The rationale here is that the alphanumeric signs provide shorter legibility distances and therefore must be brighter to afford legibility distance equivalent to the recognition distance for the less bright symbol signs. Strategy 6 considered both criticality and sign type when selecting the performance standard. The Sivak and Olson values are used for critical alphanumeric signs. Fifty percent of these values are used for less critical alphanumeric signs and for critical symbol signs, and 25 percent of the recommended values are used for the less critical symbol signs.

Table 1.—Sign replacement criteria for illustrative strategies

Replacement strategy	Criteria: Criticality ≤2	Criticality >2	Type: Symbol	Type: Alpha	Performance standard SIA by location (cd/1x/m²): Right	Left	Median	Overhead
#1	ALL SIGNS				24	90	24	114
#2	ALL SIGNS				18	68	18	84
#3	ALL SIGNS				12	45	12	57
#4	X				24	90	24	114
		X			12	45	12	57
#5				X	24	90	24	114
			X		12	45	12	57
#6	X			X	24	90	24	114
		X		X	12	45	12	57
	X		X		12	45	12	57
		X	X		6	23	6	29

1 cd/1x/m² = 0.0085 cd/fc/ft²

Results

To produce a single value to compare with the SMS output, it was necessary to use the median judgment from the subject group. The panelists agreed on the majority of the signs. However, for 19 of the 65 signs (29 percent) in the inventory, more than 2 members disagreed with their peers. This disagreement may reflect the differences in criticality each individual places on a sign, which may explain some of the differences between the model and the subjects' judgments. Also, the SMS decisions are made on the basis of SIA, whereas the subjects made their judgments based on available luminance and personal subjectivity and knowledge.

The results of the comparison between the strategies and the panel ratings were broken down into four categories:

- Match/Replace—Signs that both the strategies and the panel agreed should be replaced.
- Match/Retain—Signs that both the strategies and the panel agreed should not be replaced.
- Miss/Replace—Signs that the strategies selected for replacement and the panel judged as not needing replacement.
- Miss/Retain—Signs that the strategies indicated did not need replacement and the panel judged as needing replacement.

Although none of the "misses" is desirable, the miss/retain errors are more significant than are the miss/replace errors. Miss/replace increases costs by replacing signs that still may be adequate, but miss/retain creates potential liability by not replacing a sign that does not provide sufficient retroreflectivity.

The results of the comparison of the six strategies with the panel judgments are shown in table 2.

Table 2.—Comparison of replacement strategies and panel judgments

	Panel	Strategy 1	2	3	4	5	6
Match/Replace	18	17	14	11	12	14	10
Match/Retain	47	38	41	42	39	41	42
Miss/Replace	—	9	6	5	8	6	5
Miss/Retain	—	1	4	7	6	4	8
Cost in dollars	1,164	1,290	1,074	678	930	978	642

If the results are examined from the standpoint of the total number of matches, all of the strategies have overall rates between 77 and 83 percent—an insignificant difference. However, considering the number of misses, Strategy 1, being the most conservative, has a miss/retain rate of less than 2 percent while the other strategies range between 6 and 12 percent.

The cost associated with the strategies also must be taken into account in the evaluation. The SMS will provide an estimated cost for sign replacement for the strategy selected. This cost is based on the square inches of sheeting material to be replaced.

Based on the data presented, one strategy cannot be judged to be the best. For a particular jurisdiction, the accuracy of each strategy versus its cost must be weighed to select the best strategy. However, considering the cost of having a panel visually check each sign, using Strategy 1 with the SMS not only results in a cost savings but also results in new signs for those signs that may be of questionable effectiveness. This outcome is advantageous when considering the motorist as well as when considering tort liability.

Further, the use of the SMS to identify replacements will result in more uniform luminance values across jurisdictions because human judgment variation, evident in the subject panel, is removed from the decision process.

Conclusions and Recommendations

The results of the field evaluation demonstrate that sign replacement strategies based primarily on SIA and used with the SMS in its present form produce sets of replaced signs that compare favorably with those produced by expert subjects. As it exists, the SMS could provide an effective tool for use by State or local agencies. However, the application of the procedure requires that an agency compile a sign inventory that includes retroreflectometer SIA information. Acquiring reflectometer readings for every sign is a labor-intensive approach to sign replacement decisions.

The final version of the SMS is being designed as a system that uses the four models together with the sign inventory data base to predict the signs that will require maintenance. Field measurements will spot check the replacement recommendations being made by the SMS and calibrate the deterioration model to the conditions that exist in the specific jurisdiction. A National Cooperative Highway Research Program study will develop a prototype instrument to measure sign retroreflectivity from the work vehicle without having to press the instrument against the sign face as presently is required with a retroreflectometer. This would simplify the data collection task significantly.

The study discussed in this article has assembled the framework for a truly effective SMS. The input mechanism for the sign inventory and road file data bases has been developed and an extensive sign dictionary has been compiled.

Currently, the SMS is only available for use on a DEC PDP11 microcomputer system. An IBM-compatible version of the SMS is being developed at this time and should be available later this year. For more information about the SMS, contact:

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Roadside Safety—A National Perspective

by
Lawrence McCarthy

Introduction

Each year millions of persons are killed or seriously injured in motor vehicle accidents. In 1984, more than 46,000 people died in motor vehicle traffic accidents and another 1,700,000 persons suffered seriously disabling injuries. It is estimated that 200 persons are killed or seriously injured every hour on United States' roadways and that traffic accidents are the leading cause of death for persons age 1 to 37. (*1*)[1]

Although significant progress has been achieved in the past 20 years in reducing the number of traffic-related deaths per vehicle mile of travel (VMT), accident costs continue to increase. The societal costs associated with traffic accidents, including lost wages, property damage, insurance, and medical costs, have risen from $10 billion in 1965 to over $50 billion in 1985. Accident costs per VMT have risen 250 percent during this same period. (*1*)

An examination of the traffic fatality distribution for 1984 by most harmful event (fig. 1) shows the serious consequences of run-off-the-road accidents. (*2*) On all roadways, over 36 percent of the fatalities were caused by striking roadside objects such as trees, poles, and embankments. Similarly, a roadside object was judged to be the most harmful event in 47 percent of the fatalities on the Interstate system. Furthermore, an examination of single-vehicle accident fatalities on the Interstate system (fig. 2) reveals that nearly one-third of the fatalities were caused by a vehicle striking a longitudinal barrier and another one-third were caused by vehicle rollover. (*2*) Clearly, single-vehicle accidents represent a major highway safety problem with massive societal costs.

Efforts to Improve Roadside Safety

The Federal Highway Administration (FHWA) annually authorizes expenditure of between $1 billion and $2 billion in Federal-Aid Highway Safety Funds. (*3*) These funds are distributed to the States for hazard elimination programs, including elimination of hazards at rail-highway crossings, and various highway safety programs. Considerably more funds for safety features are incorporated into noncategorical Federal-Aid and State highway construction. Within the Federally Coordinated Program (FCP)—FHWA's management framework and coordinating mechanism for the separate programs—FHWA also administers significant efforts in

[1]Italic numbers in parentheses identify references on page 128.

research, development, and technology sharing. The FHWA Offices of Research, Development, and Technology are assigned the responsibility of monitoring a number of separate elements under the FCP structure including the State Highway Planning and Research Program (HP&R), the National Cooperative Highway Research Program (NCHRP), the FHWA Administrative Contract Program, and the FHWA Staff Research Program.

In fiscal year 1985, a total of $78 million was spent in the FCP program, including approximately $15 million spent on safety-related activities (fig. 3). These safety funds are distributed among eight different FCP projects. Project 1T "Roadside Safety Hardware" accounted for approximately one-third of these safety funds. (*4*)

Project 1T research and development efforts have resulted in significant accomplishments in the design of traffic barriers and terminals, signs and luminaire supports, and impact attenuators. Recent highlights include the following:

- A self-restoring barrier (SERB) that can safely redirect vehicles ranging from an 1,800-lb (0.82-Mg) car to a 40,000-lb (1.81-Mg) intercity bus.
- A controlled releasing terminal (CRT) for straight sections of guardrail that significantly reduces roll and yaw forces on small cars.
- A vehicle attenuating terminal (VAT) that provides a safe terminal where the guardrail end cannot be flared.
- An 1,800-lb (0.82-Mg) bogie vehicle built and validated for testing breakaway supports at the Federal Outdoor Impact Laboratory (FOIL) at the Turner-Fairbank Highway Research Center in McLean, Virginia.

Project 1T efforts also have provided analysts online computer access to a variety of vehicle-barrier simulations, including HVOSM, BARRIER VII, and an updated CRUNCH program. These programs and other analytical tools allow analysts to economically assess the performance of safety appurtenances.

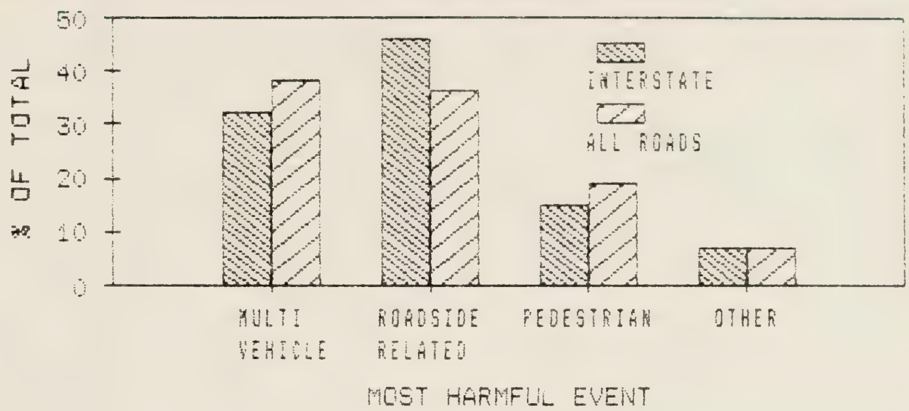

Figure 1.—1984 traffic fatality distribution—all roadways. (2)

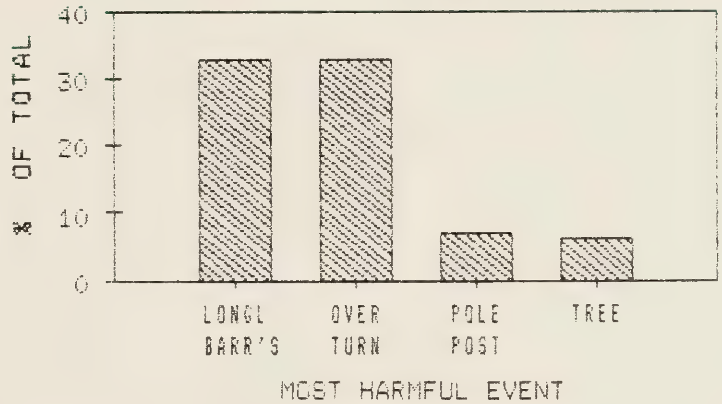

Figure 2.—Single-vehicle fatalities on the Interstate system. (2)

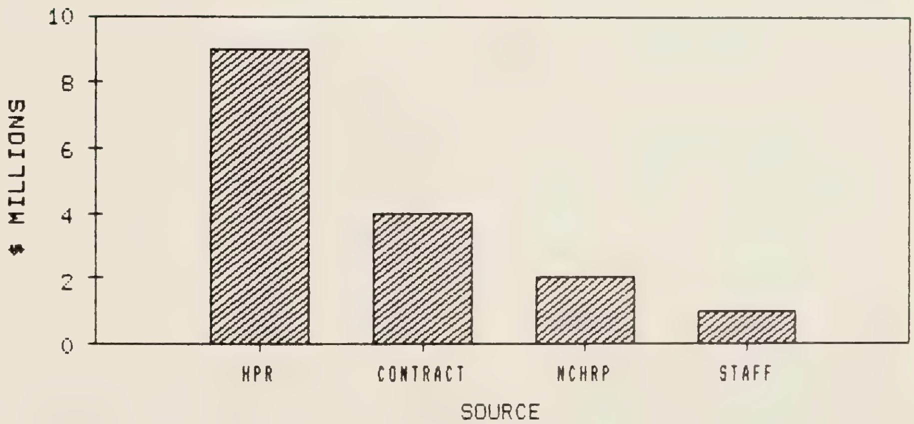

Figure 3.—FCP safety funding by source. (4)

Another significant accomplishment in the area of cost-effective roadside safety design has been the development of improved analysis methods for justifying safety improvements and maximizing safety benefits. The use of improved computerized benefit-cost procedures, including integer programming, dynamic programming, and incremental benefit-cost methods, results in significantly greater net benefits than do the simple benefit-cost procedures (fig. 4). (*5*)

Problems in the Design of Safer Roadsides

Warranting criteria

Cost-effective treatments for run-off-the-road accidents require warranting criteria based upon accident and/or encroachment models and an effectiveness estimate of the planned countermeasure. That is, to quantify the expected benefits of a safety improvement, estimates are needed as to the expected number and type of vehicle impacts with the safety hardware. This information then can be related to the results from full-scale crash testing to estimate the benefits expected from reducing the severity of run-off-the-road accidents.

To develop warrants for roadside hardware, the encroachment or run-off-the-road accident rate and type must be defined as a function of highway geometry and traffic distribution. As a minimum, these data should include vehicle speed, vehicle departure angle, and the lateral distance traveled from the edge of the roadway. The following two approaches have been used to compile this information:

- Encroachment model—Vehicle departures from the roadway are charted and a distribution is compiled. The data collection techniques range from remote sensing equipment to manual observation of vehicle tire tracks off the roadway.
- Accident model—Single-vehicle accidents are investigated and reconstructed by a team of specialists to compile the data.

Figure 5 highlights the problems associated with compiling data on these characteristics. (*6-8*) Note that the 50th percentile departure angle ranges from 8 to 18 degrees, and the 85th percentile ranges from 20 to 40 degrees. In general, departure angles are more severe if an accident model is used because only more severe accidents will be investigated. Reliance on such an approach will bias the distribution of both angle and speed toward more severe departures.

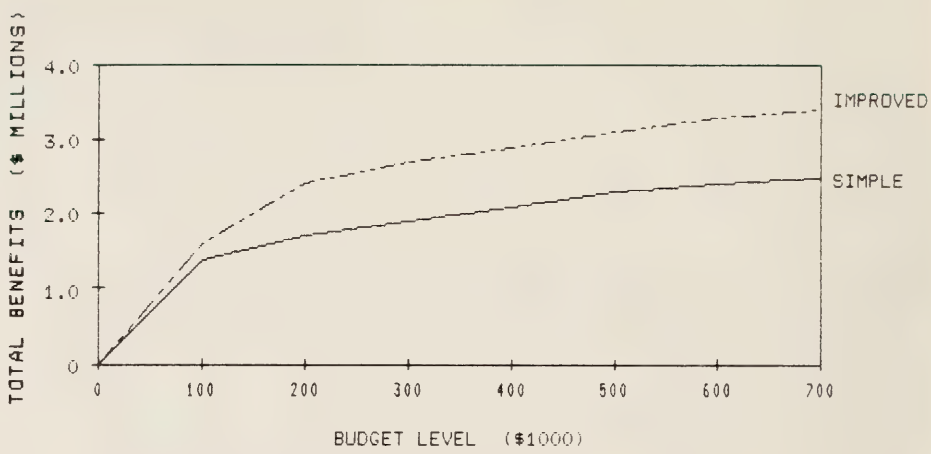

Figure 4.—Benefit-cost methods. (5)

The encroachment model's main drawbacks are the expense and difficulty involved in collecting data. FHWA recently spent more than $800,000 in a study to collect encroachment data. (*7*) Various techniques were used, including continuous monitoring of highway sites with videotape recorders, remote sensing equipment, and tape switch-activated movie cameras. From the 36,000 hours of videotape data (approximately 4.1 years), only 12 encroachments were recorded for analysis.

It also should be noted that reliance on manual methods of data collection will not furnish departure speed or vehicle type. Furthermore, there is some evidence that such methods will overestimate encroachment rates by counting vehicle departures when the driver intentionally steers off the roadway (that is, a controlled encroachment). Currently, no definitive data exist on these essential elements required for warranting criteria.

Hardware acceptance standards

Roadside hardware is subjected to full-scale crash tests before its acceptance for deployment in the field. The acceptance standards are based upon the appurtenance's structural adequacy, the resulting occupant risk, and the vehicle's after-collision trajectory. (*9*) At issue is whether the current set of test matrices accurately reflects the real-world accident characteristics. This is a critical factor in evaluating the hardware's anticipated effectiveness.

Recent analysis of investigated injury accidents at narrow bridge sites related the actual accident impact conditions to the conditions imposed in crash test matrices. As shown in figure 6, a large number of these severe accidents exceeded at least one of the crash test conditions.[2]

Although these investigated accidents represent a very small sample (n = 81) of injuries and fatalities, the data provide important insight into the actual dynamics of run-off-the-road accidents. In 70 percent of the reconstructed accidents from figure 6, the vehicle sustained a secondary impact following a smooth redirection from the initial impact with the barrier. Such secondary impacts tend to dramatically increase the occupant risk because of higher impact angles, the vehicle not tracking at impact, a collision with unprotected fixed objects, and vehicle rollover.

Figure 7 shows that vehicle rollover and secondary impacts with fixed objects subsequent to the first barrier impact constitute a major safety hazard. (*2*) Therefore, the importance of the vehicle's post-impact trajectory in current hardware acceptance criteria cannot be overemphasized.

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[2]J.D. Michie, "Evaluation of Design Analysis Procedures and Acceptance Criteria for Roadside Hardware," Federal Highway Administration, Washington, DC. Not yet printed.

Finally, in addressing the current hardware acceptance standards in terms of cost-effective design, impact speed distribution should be examined as a function of roadway type. Figure 8 shows three such distributions compiled from narrow bridge and pole accident data bases. If the hardware acceptance standard is based on the 85th percentile impact speed, the appropriate crash test speed will range from 40 mi/h (64 km/h) on urban arterials to 60 mi/h (97 km/h) on freeways. Clearly, the data indicate the desirability of using a multi-performance level approach to roadside safety design to maximize the benefit-cost ratio for safety-related improvements.[3]

Implementing, installing, and maintaining roadside hardware

In addition to the problems already discussed, difficulties experienced in implementing, installing, and maintaining roadside hardware continue to trouble the highway safety practitioner. In general, each roadside safety appurtenance proceeds through four separate stages before reaching full-scale implementation—design, testing, experimental deployment, and inservice evaluation. Given the iterative nature of these stages, it is often more than 10 years from the initial conception of new technology to its full-scale implementation. Even with a smooth transition through the evaluation stage, there is no guarantee that full-scale implementation will follow. Given the seriousness of the roadside safety problem confronting us today, reducing the time required to implement improved safety technology should be a priority.

Improper installation and maintenance of safety hardware constitute a major safety hazard to the driving public as well as an increased liability burden for State and local agencies. Recent examples include the following:

- Deformable guardrails installed within 8 in (203.2 mm) of nonbreakaway poles to shield the poles.

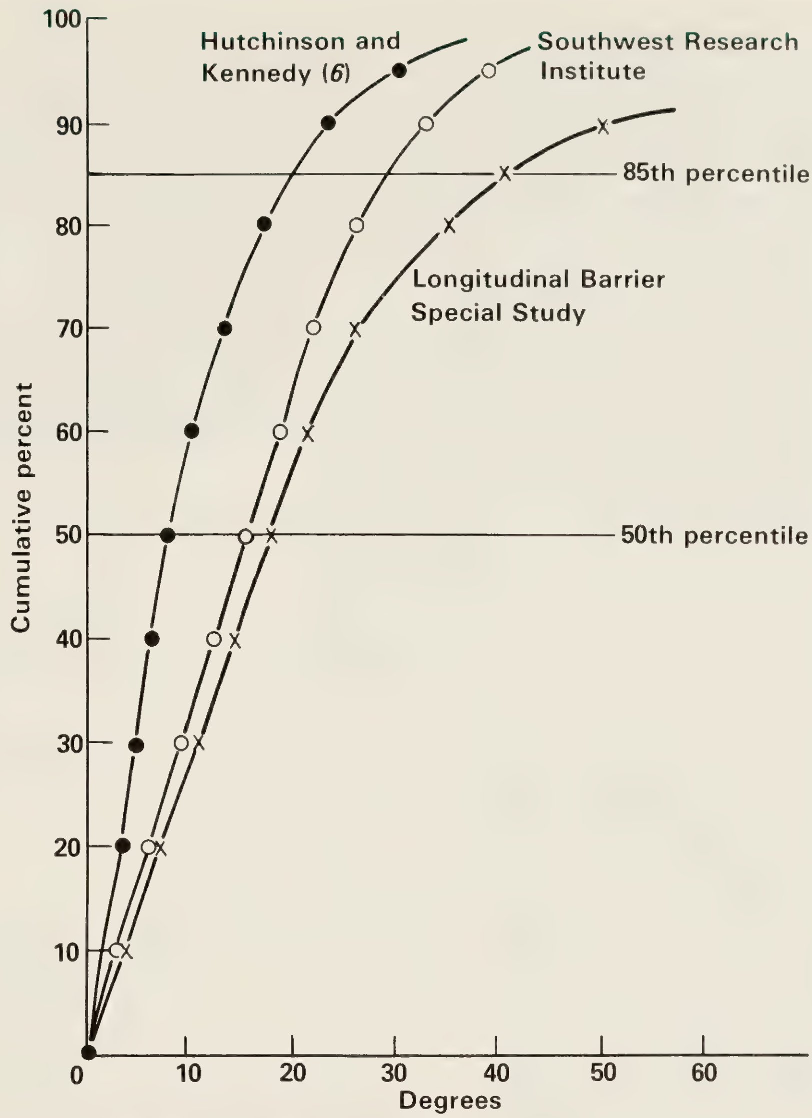


Figure 5.—Run-off-the-road departure angles. (6-8)

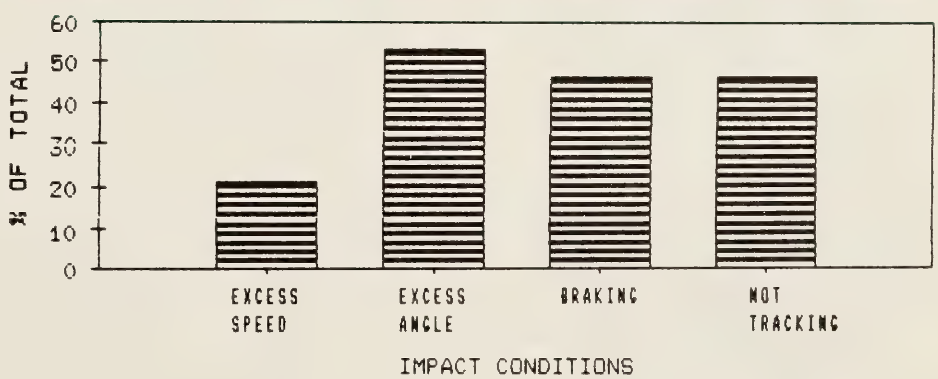


Figure 6.—Investigated accidents.

[3]K.K. Mak et al., "Real-World Impact Conditions for Run-Off-the-Road Accidents," Paper presented at the 65th annual meeting of the Transportation Research Board, Washington, DC, January 1986.

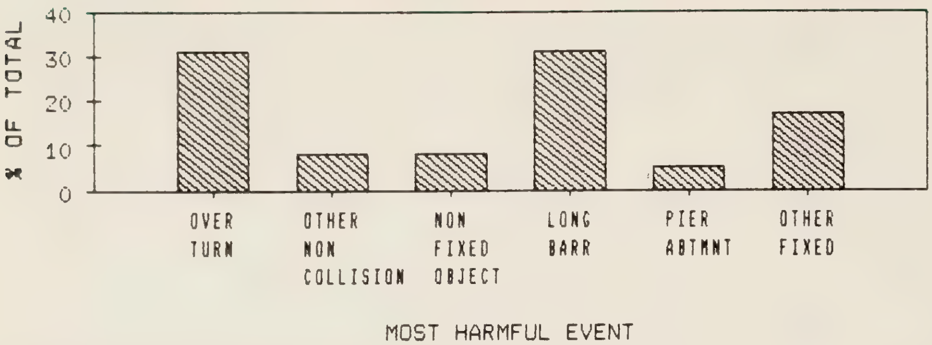


Figure 7.—Fatalities where first object struck is longitudinal barrier. (2)

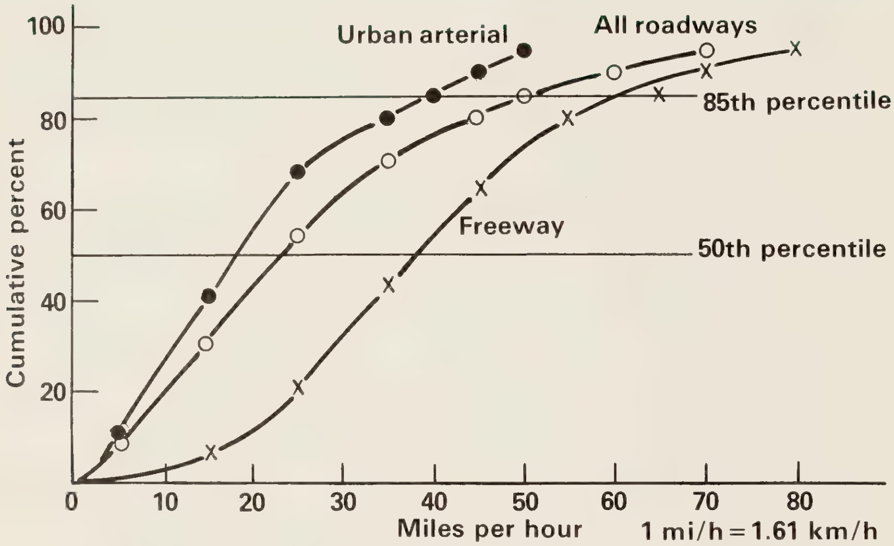


Figure 8.—Speed at impact.

- Improper transitioning between rigid bridge rails and the deformable approach guardrail.
- Improper use of washers (on the first 37.5 ft [11.4 m]) on breakaway cable terminals (BCT), resulting in significant performance degradation.

Summary

Although powerful procedures and analytical tools to cost-effectively design safer roadsides have been developed, critical gaps in the input data continue to undermine researchers' efforts. Careful investigation of the available data indicates that hardware acceptance criteria need closer attention to ensure their accurate reflection of the real-world dynamics of single-vehicle accidents. The high incidence of multiple-impact accidents graphically demonstrates the significance of this need. These difficulties are compounded by the delays experienced in the deployment of effective hardware as well as by the complications arising from improper installation and maintenance. Continued research, development, and technology sharing are needed to address the roadside safety problem.

REFERENCES

(*1*) "Accident Facts, 1985 Edition," *National Safety Council,* Chicago, IL, 1986.

(*2*) "Fatal Accident Reporting System (FARS)," Online data base maintained by the *National Highway Traffic Safety Administration*, 1982, 1983, 1984.

(*3*) "Highway Statistics 1983, "*Federal Highway Administration*, Washington, DC, October 1985.

(*4*) "1984-1985 Report of the Offices of Research, Development, and Technology," *Federal Highway Administration*, Washington, DC, December 1985, p. 34.

(*5*) W.F. McFarland and J.B. Rollins, "Cost-Effectiveness Techniques for Highway Safety: Resource Allocation," Report No. FHWA/RD-84/011, *Federal Highway Administration*, Washington, DC, June 1985. PB No. 85 219194.[4]

(*6*) G.W. Hutchison and T.W. Kennedy, "Medians of Divided Highways—Frequency and Nature of Vehicle Encroachments," *University of Illinois Engineering Experiment Station*, Bulletin 487, Urbana, IL, 1966.

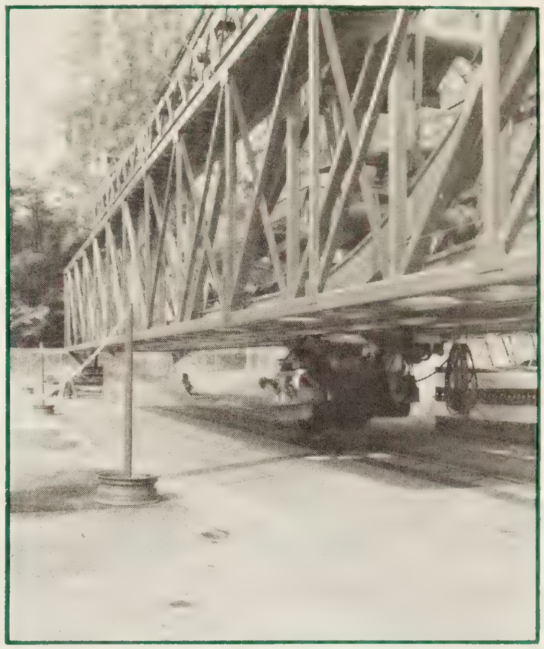
(*7*) R.L. Calcote et al., "Determination of the Operational Performance Requirements for a Roadside Accident Countermeasure Warrant System," Report No. FHWA/RD-85/113, *Federal Highway Administration*, Washington, DC, October 1985. PB No. 86 126281.

(*8*) "Longitudinal Barrier Special Study (LBSS)," the National Accident Sampling System, Data base maintained by the *National Highway Traffic Safety Administration,* 1982.

(*9*) J.D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report No. 230, *Transportation Research Board,* Washington, DC, March 1981.

Lawrence McCarthy is a highway research engineer in the Safety Design Division, Office of Safety and Traffic Operations R&D, FHWA. Currently, he is involved in accident research and large-truck safety research.

[4]Reports with PB numbers may be purchased from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.



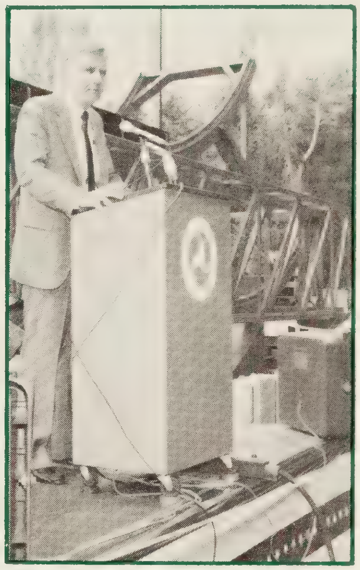
Pavement Testing Facility at the Turner-Fairbank Highway Research Center

On October 24, 1986, the Federal Highway Administration (FHWA), Offices of Research, Development, and Technology (RD&T) held an open house at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia, to dedicate the recently completed Pavement Testing Facility (PTF).

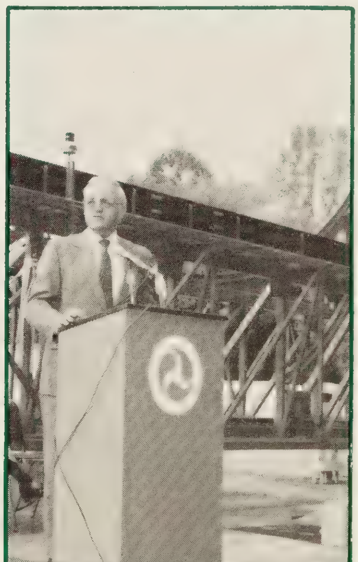
The PTF will contribute to a better understanding of pavement structures and how they perform by providing the capability to test full-scale pavements with simulated truck traffic. In a few months, a pavement test section at the facility can receive the same loading that may require up to 20 years of actual service on a highway. The facility includes the Accelerated Loading Facility (ALF) machine, which can apply dual-truck tire loads ranging from 9,000 to 22,500 lb (4.1 to 10.2 Mg) at the rate of 8,500 load applications per day. The dual-tire assembly moves at 12.5 mi/h (20 km/h) and can test a pavement section 33 ft (10.1 m) long. The routine operating schedule of the ALF at the TFHRC will be 20 to 22 hours per day, 7 days a week.

The ALF has several unique design features: Low operating energy requirements resulting from the use of gravity to accelerate and decelerate the test wheel assembly, single-direction loading, variable transverse load distribution, and all-weather operation. In addition, the ALF is fully transportable for field testing real-world pavements.

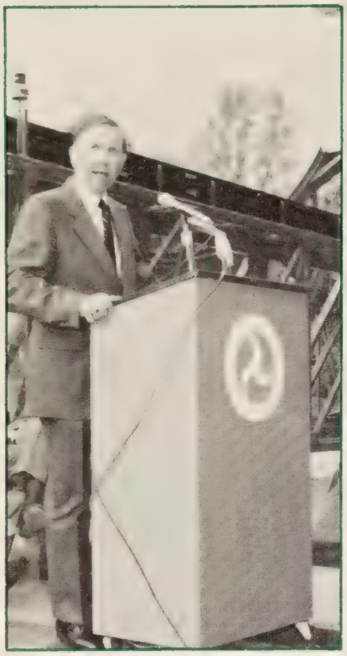
The ALF is the second of its kind in the world. The prototype was designed and constructed by the Department of Main Roads, New South Wales, Australia. The Australian ALF, owned by the Australian Road Research Board, has been in nearly continuous operation since July 1984 and has completed approximately 4 million load applications while field testing nine Australian pavement designs.



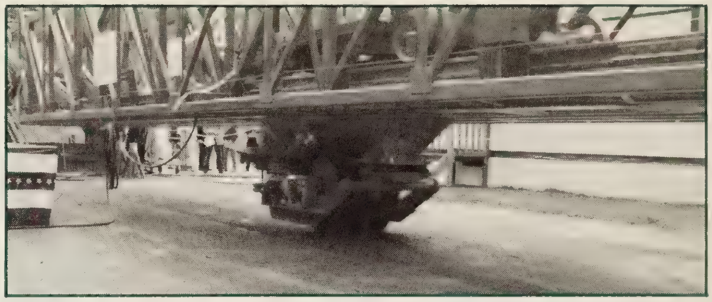
David K. Phillips, Associate Administrator for Research, Development, and Technology, welcomed guests to the ceremony dedicating the Pavement Testing Facility.



Federal Highway Administrator R.A. Barnhart spoke at the dedication ceremony.



Richard E. Hay, Director, Office of Engineering and Highway Operations Research and Development, detailed the operation of the ALF.



The ALF's dual-tire assembly can administer wheel loads ranging from 9,000 to 22,500 lb (4.1 to 10.2 Mg) at the rate of 8,500 applications per day.

Improvements to the U.S. ALF include a transfer rail system that allows easy access to the test pavement, an emergency jacking system, and a U.S. electrical control and data acquisition system.

The other components of the PTF are the two bituminous concrete test pavements. Test lane 1 currently consists of a 2-in (50.8-mm) wearing course on 3 in (76.2 mm) of binder, which is on 5 in (127 mm) of a crushed aggregate base course. Test lane 2 currently consists of a 2-in (50.8-mm) wearing course on 5 in (127 mm) of binder, which is on 12 in (304.8 mm) of aggregate base. Both pavements are constructed on a uniform 3-ft (0.9-m) thick select borrow soil subgrade. Pavement data acquisition and storage will be performed by a full-time dedicated microcomputer.

The PTF will be available to generate pavement performance data for the Asphalt Characteristics and Long-Term Pavement Performance Programs under the Strategic Highway Research Program (SHRP). Beyond providing support to SHRP, the PTF's capabilities can be used to validate and refine mechanistic models, correlate laboratory test results, examine the effects of increased axle loading and the effects of increased tire pressure on pavements, evaluate rehabilitation strategies for pavements, and verify and improve design models.

The ALF, part of the Pavement Testing Facility at the Turner-Fairbank Highway Research Center in McLean, Virginia, simulates truck traffic on a full-scale pavement.

The PTF will provide a unique testing capability in the United States by bridging the gap between the laboratory and computer models and real-world pavement performance.

At the October dedication ceremony, David K. Phillips, Associate Administrator for RD&T, welcomed the approximately 200 FHWA employees and representatives from Congress, highway associations, other Federal agencies, and local universities. He then introduced Federal Highway Administrator R.A. Barnhart. After Mr. Barnhart's brief remarks, Richard E. Hay, Director, Office of Engineering and Highway Operations Research and Development, discussed the facility in greater detail and demonstrated the operation of the ALF. FHWA Executive Director R.D. Morgan then pushed the button to start the ALF machine to officially signal the initiation of the new test facility.

In his closing remarks, Mr. Phillips invited the visitors to witness a demonstration at the Federal Outdoor Impact Laboratory (FOIL), another major laboratory at the TFHRC. The FOIL is used to test roadside hardware design in an effort to minimize the severity of roadside collisions. It is the only facility of its kind that can test side impacts between an automobile and roadside hardware.

Visitors also toured the Center's other laboratories where studies are conducted on hydraulics, human factors, structures, soils, asphalt, concrete, and aerodynamics of structures.

Visitors saw a crash test demonstration using the bogie vehicle at the Federal Outdoor Impact Laboratory at the Turner-Fairbank Highway Research Center.

Recent Research Reports You Should Know About

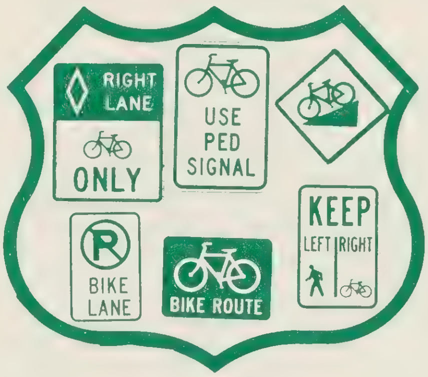
The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Offices of Research, Development, and Technology (RD&T). The Office of Engineering and Highway Operations Research and Development (R&D) includes the Structures Division, Pavements Division, and Materials Division. The Office of Safety and Traffic Operations R&D includes the Traffic Systems Division, Safety Design Division, and Traffic Safety Research Division. The reports are available from the source noted at the end of each description.

Requests for items available from the RD&T Report Center should be addressed to:

Federal Highway Administration
RD&T Report Center, HRD-11
6300 Georgetown Pike
McLean, Virginia 22101-2296
Telephone: (703) 285-2144

When ordering from the National Technical Information Service (NTIS), use PB number and/or the report number with the report title and address requests to:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161



Highway Route Designation Criteria for Bicycle Routes: Final Report, Report No. FHWA/RD-86/066

by Safety Design Division

This report discusses a study that surveyed the literature and state-of-the-art related to bicycle route selection and designation and developed a synthesized set of factors for use by State and local transportation officials and other agencies involved in the selection and designation of streets and highways for bicycle use. The background of bicycle use is presented, the major factors related to route alignment and route suitability are identified, and the processes involved in route selection and the options available for route designation are discussed. Four special topics also are treated—the use of controlled access freeway shoulders by bicycles, research needs related to bicycle route selection and designation, liability aspects of bikeway designation, and bicycle mapping.

Other results of the study are presented in a handbook, report No. FHWA-IP-86-12 (see page 134).

The report may be purchased from NTIS (PB No. 86 236684).

Influence of Size and Weight Variables on the Stability and Control Properties of Heavy Trucks, Report No. FHWA/RD-83/029

by Safety Design Division

This report discusses a study to determine the influence of variations in truck size and weight constraints on the stability and control properties of heavy vehicles. The size and weight constraints include axle load, gross vehicle weight, length, width, kind of multiple-trailer combinations, and bridge formula allowances. Variations in location of the center of gravity of the payload also were considered. The influence of these parametric variations on stability and control behavior was explored by full-scale vehicle tests and computer simulations. For each size and weight "issue" the stability and control problem areas are addressed and the influence of size and weight variations is quantified. The results then are reviewed for their potential implications for traffic safety.

Limited copies of the report are available from the RD&T Report Center.

Performance Limits of Longitudinal Barrier Systems, Vol. I, Summary Report, Report No. FHWA/RD-86/153

by Safety Design Division

This report discusses a study that evaluated the performance limits of guardrails, median barriers, and embankments for different classes of vehicles and impact conditions. The study consisted of accident data analyses, computer simulation work, measurement of inertial properties of vehicles, full-scale crash tests of longitudinal barriers, and full-scale embankment traversal tests.

Limited copies of the report are available from the RD&T Report Center.

A Relative Effectiveness Analysis of a Selected Fixed Lighting System Versus Vehicle Headlights, Report No. FHWA/RD-86/033

by Traffic Safety Research Division

This report discusses an evaluation of the relative effectiveness of a selected fixed lighting system and vehicle headlights in providing the visual inputs needed by drivers to detect a defined category of roadway hazards. Key parameters in the analysis included the position (distance and orientation) of a vehicle operator with respect to a detection target in the roadway, the characteristics (size, shape/configuration, reflectivity) of the detection target, the reflectance characteristics of the road surface, the estimated target and background luminance levels for a fixed lighting system, the estimated target and background luminance levels for a vehicle-based source of illumination, and the position of opposing vehicles (if any) with respect to an observer/driver. A conceptual model incorporating published decision-sight-distance (DSD) formulations was used.

Calculations indicated a marked superiority for fixed lighting systems as observer-target separation distance is increased and/or target reflectivity is decreased and/or an opposing vehicle is present and located (longitudinally) between the observer and the detection target/hazard. Road surface reflectance characteristics had a comparatively smaller impact on the present relative effectiveness calculations.

The report may be purchased from NTIS (PB No. 86 206133).

Impact of Arterial Lane Obstructions, Vols. I-III, Report Nos. FHWA/RD-86/138-140

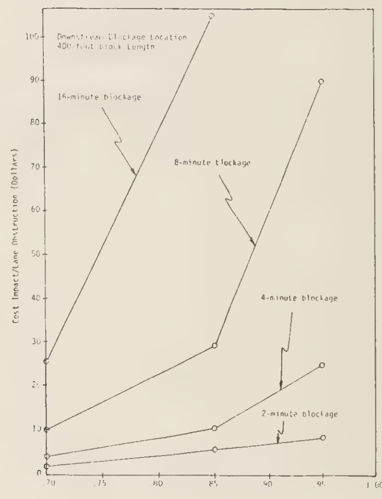
by Traffic Systems Division

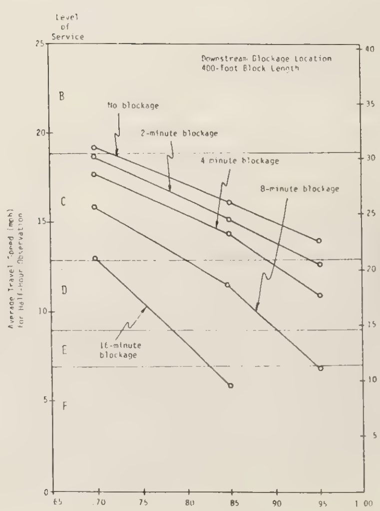
The impact of lane obstructions—traffic events that block traffic lanes and impede the movement of vehicular traffic—has not been well defined in the past. These reports discuss a study conducted to develop simple and accurate methods for estimating the impacts of lane obstructions on traffic flow on arterial streets.

The lane obstruction logic in the NETSIM model was modified and calibrated, using newly collected and other existing photographic film data, to represent corresponding situations in the field.

The enhanced NETSIM model then was applied to develop a set of curves that represent the dollar cost impacts and the level of service resulting from lane obstructions for various street and traffic conditions. The result is a relatively simple method for estimating the impacts of lane obstructions. Examples in the three reports—**Volume 1, User's Guide for Controlling Lane Obstructions; Volume 2, Research Report; and Volume 3, Lane Blockage Logic Changes Made to NETSIM**—illustrate the application of the method.

The reports may be purchased from NTIS (PB Nos. 86 199700, 86 199718, and 86 199726).





Minimal Luminance Requirement for Official Highway Signs, Executive Summary, Report No. FHWA/RD-86/150, and Final Report, Report No. FHWA/RD-86/151

by Traffic Systems Division

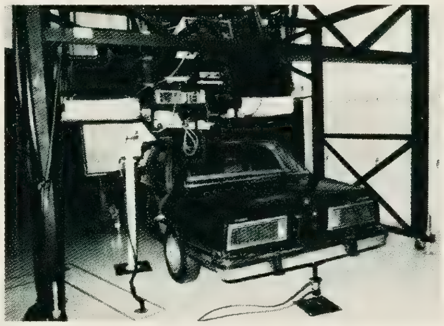
These reports discuss a study to establish minimal levels of sign luminance for various signing applications and conditions and to develop a structure for determining sign maintenance priorities. The objectives were addressed by developing a system for maintenance of sign reflectivity with luminance standards embedded in the system. The problem of implementing luminance standards is presented, as is a discussion of the factors essential to a computer-based system for implementing reflectivity standards. A decision-support system developed for the management and maintenance of sign inventories is described, and an empirical study that evaluated several aspects of the system is discussed. The results showed that use of the system for making decisions about sign replacement based on specific intensity per unit area (SIA) produces decisions comparable to those obtained from experts making personal inspections. Additional research needed is outlined.

The reports may be purchased from NTIS (PB Nos. 86 236569 and 86 236577).

A Validation Study of the DOT/FHWA Highway Simulator (HYSIM), Report No. FHWA/RD-86/067

by Traffic Systems Division

The study discussed in this report compared driver performance data from a simulated roadcourse in the DOT/FHWA Highway Simulator (HYSIM) with data gathered on actual real-world roadways. Thirty-two subjects from the general driving population participated in the study. Dependent variables included sign detection and recognition distances, speed, accelerator position changes, and steering wheel reversals. A high correspondence between real-world and HYSIM data sets indicated which simulator measures are valid; conversely, a low correspondence pointed to design and operational parameters that require enhancement and/or adjustment to improve HYSIM's capability to accurately simulate real-world driving.



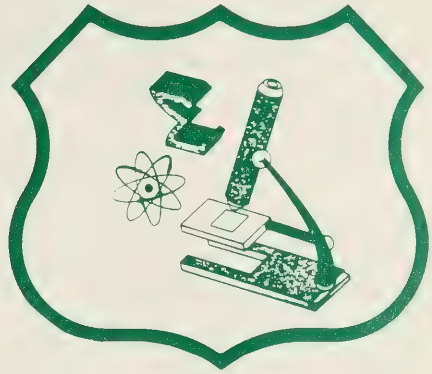
The study results show that, in general, the HYSIM measures tested accurately simulate real-world conditions, and simulated data can be safely generalized to real-world situations. However, important system constraints must be accommodated in the experimental design for studies conducted on the simulator. Those areas where enhancement and/or system modifications are required or are desirable are identified, and recommendations for solving these problems are provided.

The report may be purchased from NTIS (PB No. 86 211778).

Development of Strength in Cements, Report No. FHWA/RD-86/002

by Materials Division

Part 1 of this three-part interim report is concerned with strength development in mortars with additions of silica fume. The addition of silica fume and superplasticizer to a mortar mix increases the strength development and shrinkage. Belite cements blended with silica fume, expansive clinker or C_4A_3S and gypsum with an addition of superplasticizer can provide fast strength development with an accompanying low-drying shrinkage. Water demand for workability, setting time, and drying shrinkage are reduced by a partial substitution of silica fume with expansive clinker or C_4A_3S and gypsum in blended cement mortars; drying shrinkage is reduced.



Part 2 of the report discusses the preparation of dicalcium silicate at 1,234 K (961 °C) or lower temperatures. The only product of heating a $CaC_2O_4 \cdot H_2O + CaCo_3 + SiO_2$ mixture for 3 hours at 1,223 K (950 °C) in a CO_2 environment was β-Ca_2SiO_4(β-C_2S)[2]. Heating at 1,033 K (760 °C) the products were β-C_2S, CaO, $CaCO_3$, and unreacted SiO_2. Heating at 1,123 K (850 °C) gave β-C_2S and small amounts of CaO and CaS_2O_3. There were also studies of products obtained by reacting the mixture at other temperatures and also in an oxygen environment.

Part 3 of the report discusses phases in the system Ba_2SiO_4-Ca_2SiO_4. Six phases exist in the whole range of the system Ba_2SiO_4-Ca_2SiO_4, which are denoted as Ba_2SiO_4, T, X, α, β, and γ-Ca_2SiO_4 in this report. The sole presence of each occurs at the following matching concentrations, of 0, 20, 60, 85, 95, and 100 weight percent of Ca_2SiO_4 in the raw mix, respectively. The various phases and transformations were identified with differential thermal analyses (DTA) and x-ray diffraction techniques.

The report may be purchased from NTIS (PB No. 86 179637).

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

The following are brief descriptions of selected items that have been completed recently by State and Federal highway units in cooperation with the Office of Implementation, Offices of Research, Development, and Technology (RD&T), Federal Highway Administration. Some items by others are included when the items are of special interest to highway agencies.

Requests for items available from the RD&T Report Center should be addressed to:

Federal Highway Administration
RD&T Report Center, HRD-11
6300 Georgetown Pike
McLean, Virginia 22101-2296
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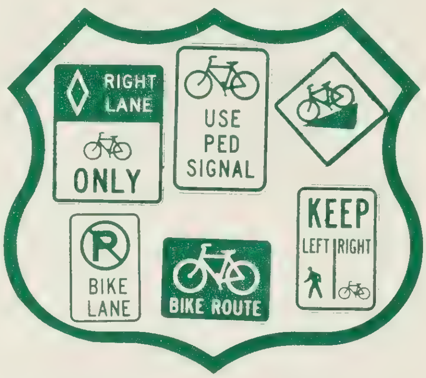


Highway Route Designation Criteria for Bicycle Routes: A Handbook, Report No. FHWA-IP-86-12

by Office of Implementation

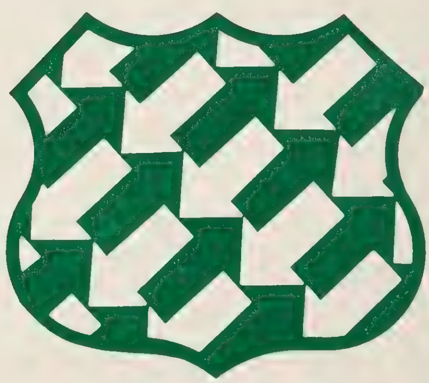
A literature survey and a survey on the state-of-the-art related to bicycle route selection and designation were conducted and a synthesized set of factors was developed for State and local transportation officials and other agencies and organizations involved in the selection and designation of streets and highways for bicycle use. The results of these efforts are presented in this handbook and a final report, Report No. FHWA/RD-86/066 (see page 131). The handbook is designed to simplify the task of selecting and designating streets and highways for bicycle routes. The topics covered include the definition of bicycle routes; the purposes, which affect suitability; approaches to planning and selecting bicycle routes; and guidelines for various route projects.

The handbook may be purchased from NTIS (PB No. 86 244431).

UTCS Functional Hardware Specifications Handbook, Report No. FHWA-IP-86-13

by Office of Implementation

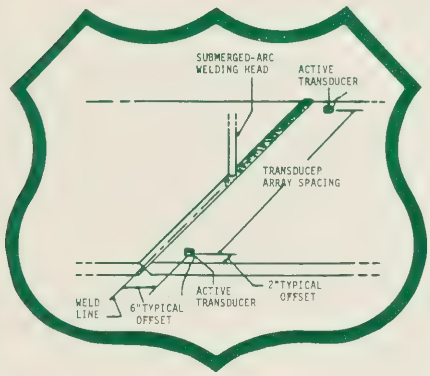
This handbook, which contains specifications for the UTCS enhanced software, provides system designers with specific information required to define a central computer-controlled traffic signal system. Specifications are included for traffic signal controllers, detectors, circuit protection, communication equipment, computers and peripherals, control and display devices, traffic application software, operating system software, and the interfaces between system elements.



In addition to hardware specifications, the handbook contains discussions of each of the system elements to help the designer decide which hardware is necessary for a system. The handbook also contains specifications for testing, training, and documentation. Both operational and maintenance facets of the system are included in the specifications. The principles of specification writing, including the organization of specifications, writing style, and wording, and a description of functional specifications also are discussed.

Limited copies of the report are available from the RD&T Report Center.

Acoustic Emission Weld Monitor Field Evaluation, Report No. FHWA-TS-86-202



by Office of Implementation

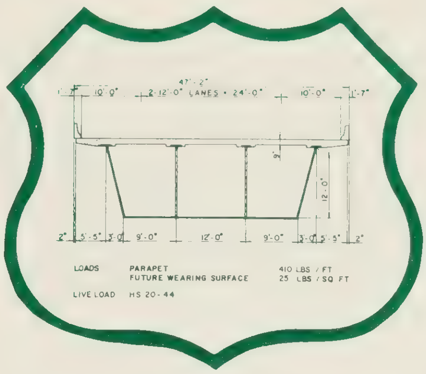
This report describes the demonstration and preliminary evaluation of the microprocessor-based acoustic emission weld monitor (AEWM) developed for FHWA. The equipment was tested successfully on butt welds in several fabrication shops under the Kentucky Transportation Research Program. Some problems were encountered in monitoring fillet welds.

The AEWM was demonstrated to personnel from 20 State agencies representing FHWA Regions 1, 3, 4 and 5. The demonstrations were performed at three different fabrication shops in Pennsylvania, Georgia, and Wisconsin.

A preliminary evaluation of the AEWM is included in the report. Also, the summary of a questionnaire sent to the demonstration attendees is included.

The report may be purchased from NTIS (PB No. 86 235223).

Design Examples for Steel Box Girders, Report No. FHWA-TS-86-209



by Office of Implementation

This report documents the results of an evaluation of the proposed design specifications for steel box girders as presented in Report No. FHWA-TS-80-205. The results of comparative designs using the AASHTO code and the proposed specification are summarized. The differences in the designs are explained with reference to the differing design requirements of the two specifications. The practicality and ease of application of the proposed specification are discussed. The results of parametric studies to investigate the application of the proposed specification to the design of principal elements of box girders are included. The conclusions and recommendations based on the evaluation also are included.

The report may be purchased from NTIS (PB No. 86 209731).

Use of Riprap For Bank Protection-Literature Review Report, Report No. FHWA-TS-86-211

by Office of Implementation

The results of a literature review conducted to assess the state-of-knowledge on streambank protection as it relates to the design of riprap bank protection are presented in this report. Subject areas include types of riprap; design considerations (erosion mechanisms, open channel flow concepts, riprap design parameters, and equilibrium concepts); design concepts for rock riprap (extent of protection, slide slopes, armor material characteristics, stone gradation, blanket thickness, armor size, and filter design); and design concepts for other riprap types (rock window, rock and wire mattress, gabions, rubbles, pre-formed sections, grouted riprap, and concrete slabs). Based on this review, recommended guidelines for the design of riprap revetments are presented. In addition, a bibliography and glossary of design terms are included in the report.

The report may be purchased from NTIS (PB No. 86 217197).

Priority Accessible Networks for the Elderly and Handicapped in Baltimore, Report No. FHWA-TS-86-213

by Office of Implementation

This report provides results of an evaluation of priority accessible networks as a means to plan pedestrian access improvements for elderly or handicapped persons. The model was applied to three areas in Baltimore, Maryland, and 19 priority accessible network routes/zones planned. The report includes a countermeasures improvement plan for the development of the routes/zones into priority accessible networks; a descriptive evaluation of the process as it was used in Baltimore; the "before" results for the plan to evaluate the effectiveness of planned improvements in Baltimore (and the detailed evaluation plan itself); the prioritization model developed by the Baltimore investigators to aid in the ranking of needed countermeasures; and the text of a pamphlet to assist other communities in the use of the priority accessible network approach, based on the Baltimore experience with the model.

The overall result is positive; modifications are offered to make the process easier to use. The City of Baltimore has supported the results in its allocation and use of $100,000 for the installation of improvements called for in the first year of the 5-year countermeasures improvement plan.

The report may be purchased from NTIS (PB No. 86 232824).

Sound-Absorptive Highway Noise Barriers, Report No. FHWA-TS-86-214

by Office of Implementation

This report reviews theoretical, modeling, and field measurement studies of multiple reflections between parallel noise barriers and their control through the use of sound absorptive materials. Information on and examples of applications of sound absorptive noise barriers are presented with emphasis on the Japanese technology. An absorptive barrier design case study for I-440 in Nashville, Tennessee, is described in detail.

The report may be purchased from NTIS (PB No. 86 233525).

Second North American Conference on Managing Pavements

The Second North American Conference on Managing Pavements, which is being sponsored by the Ontario Ministry of Transportation and Communications and the U.S. Federal Highway Administration, is expected to draw papers and participation from decisionmakers and practitioners, consultants, academicians, researchers, and other transportation professionals from around the world.

The underlying theme of this conference will be "From Theory to Practice." It will explore practical methods and procedures that lead to better planning and management of highway pavements. Through the presentation of approximately 60 papers and the dynamic exchange of ideas in small workshops, the conference expects to provide valuable information on a number of topics. One of the primary aims of the conference will be to provide delegates with an opportunity to effectively exchange ideas in small group settings. To accomplish this, more than 50 percent of the conference time will be devoted to workshops.

The conference will present those "success stories" that illustrate how better analyses and arguments have led to the changing of internal funding priorities within an organization or to the securing of additional funding for the preservation of pavements. It will also explore many facets of managing pavements, notably new data-gathering technologies on the horizon, how microcomputers will impact and modernize pavement management, how long-term experience can be captured by expert systems, how different organizational structures affect management of pavements, the role of maintenance, and how to deal with the issues of truck weights and tire pressures. Finally, the conference will look at the challenges of the future and explore innovative ways of meeting those challenges.

The conference will be held in Toronto, Canada, on November 2-6, 1987. Those interested in writing a paper or attending the conference should contact the conference chairman for an announcement brochure.

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McLean, Virginia 22101-2296

New Research in Progress

The following new research studies reported by FHWA's Offices of Research, Development, and Technology are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description and contact the following: Staff and administrative contract research—*Public Roads* magazine; Highway Planning and Research (HP&R)—performing State highway or transportation department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, DC 20418.

FCP Category 1—Highway Design and Operation for Safety

FCP Project 1S: Design and Corrective Geometrics

Title: Centerline Striping and Wide Paved Shoulders on Two-Lane Rural Highways. (FCP No. 41S2582)
Objective: Determine the cost-effectiveness of centerline striping, and develop guidelines for the application of centerline striping on low-volume rural roads. Perform a benefit-cost study of adding wide (8 to 10 ft [2.4 to 3.0 m]) paved shoulders on two-lane rural roads. Develop guidelines for adding wide paved shoulders to new or existing two-lane rural roadways.
Performing Organization: Texas Transportation Institute, College Station, TX 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: November 1987
Estimated Cost: $91,000 (HP&R)

Title: Cost-Effective Geometric Improvements for Safety Upgrading of Horizontal Curves. (FCP No. 31S3032)
Objective: Use the results of several previous studies to evaluate appropriate retrofit alternatives for existing horizontal curve sites, including changes to superelevation, superelevation runoff, addition of paved shoulders, and improved traffic control devices. Select a sample of horizontal curve sites and match the sample with sites not having the recommended design elements. Compare accident data, speed distributions, and vehicle placement for both site types.
Performing Organization: University of North Carolina, Chapel Hill, NC 27514
Expected Completion Date: February 1989
Estimated Cost: $369,100 (FHWA Administrative Contract)

FCP Project 1T: Roadside Safety Hardware

Title: Testing of New Bridge Rail and Transition Designs. (FCP No. 31T2333)
Objective: Conduct full-scale tests on existing State standard bridge rails and transitions. Redesign and retest these bridge rails, if necessary.
Performing Organization: Texas A&M Research Foundation, College Station, TX 77843
Expected Completion Date: October 1990
Estimated Cost: $506,200 (FHWA Administrative Contract)

FCP Category 3—Highway Operations

FCP Project 3B: Environmental Management

Title: Experimental and Analytical Analysis of Blasting Criteria. (FCP No. 43B2342)
Objective: Provide guidance for setting impact limits from blasting on road soil stabilization, structural damage, and human annoyance. Evaluate legal and technical work. Develop an experimental procedure to monitor blasts by mine operators and contractors on soil near roads, pavements, and bridge structures. Make seismograph and accelerometer measurements and visual observations for test blasts at selected sites. Formulate guidelines for limiting blast impacts to highways.
Performing Organization: Ohio University, Athens, OH 45701
Funding Agency: Ohio Department of Transportation
Expected Completion Date: February 1989
Estimated Cost: $139,635 (HP&R)

FCP Category 4—Pavement Design, Construction, and Management

FCP Project 4A: Pavement Management Strategies

Title: Investigation of Rutting in Asphalt Concrete Pavements. (FCP No. 44A1522)
Objective: Evaluate the effects of high tire pressure and asphalt mix properties on rut depth. Conduct field surveys of rutted pavements and isolate the causes. Develop new materials test methods and specifications as required.
Performing Organization: Texas Transportation Institute, College Station, TX 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: September 1990
Estimated Cost: $40,000 (HP&R)

Title: Effect of Environmental Factors on Pavement Deterioration. (FCP No. 44A1532)
Objective: Determine the portion of pavement deterioration on different classes of highways caused by the environment alone (in contrast to total deterioration caused by a combination of traffic load and environment). Create a pavement deterioration responsibility model, and refine the estimate of cost responsibility for various vehicle classes based on the determination of environmental deterioration and the pavement deterioration responsiblity model.
Performing Organization: Oregon State University, Corvallis, OR 97331
Funding Agency: Oregon Department of Transportation
Expected Completion Date: August 1988
Estimated Cost: $40,000 (HP&R)

Title: Investigation of the Effects of Raising Legal Load Limits to 80,000 lb (36.3 Mg) on Farm-to-Market Roads. (FCP No. 44A3142)
Objective: Develop an efficient and practical procedure using nondestructive testing methods to determine the structural characteristics of farm-to-market roads. Evaluate the effects of the increase in the legal load limit to 80,000 lb (36.3 Mg) in terms of the reduction in design life as well as structural adequacy, and present a basis for the computation of the requirements for pavement strengthening so that load restrictions can be removed.
Performing Organization: Texas Transportation Institute, College Station, TX 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1987
Estimated Cost: $260,000 (HP&R)

Title: Texas Flexible Pavement Data Base. (FCP No. 44A3392)
Objective: Preserve, update, and improve the Texas flexible pavement data base.
Performing Organization: Texas Transportation Institute, College Station, TX 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1989
Estimated Cost: $283,000 (HP&R)

Title: Seasonal Variation for Structural Strength Values. (FCP No. 44A3494)
Objective: Apply the road rater deflection coefficient to Maine roadways. Measure during typical strength periods in summer and fall, as well as during the spring thaw when frost dissipation reduces roadway strength. Measure various subgrade soil types. Mark measurement sites to permit comparisons.
Performing Organization: Maine Department of Transportation, Bangor, ME 04401
Expected Completion Date: July 1988
Estimated Cost: $74,650 (HP&R)

FCP Project C4: Design and Rehabilitation of Flexible Pavements

Title: Materials Characterizations for Development of an Overlay Design Procedure. (FCP No. 44C1334)
Objective: Determine resilient moduli of bituminous materials, base and subbase aggregates, and subgrade materials typical of Maine through torsional testing in the laboratory for use in design of new pavements and pavement overlays. Correlate field deflection testing data with theoretical deflections, based upon the laboratory moduli determination of the study, to provide the basis for empirical adjustment factors for use in an overlay design procedure.
Performing Organization: Maine Department of Transportation, Bangor, ME 04401
Expected Completion Date: October 1988
Estimated Cost: $51,000 (HP&R)

Title: Mix Design Modification for Dense-Graded Asphalt Concrete (DGAC) Mixes to Improve Asphalt Concrete Durability. (FCP No. 44C2173)
Objective: Investigate the need of adjusting DGAC mix design criteria on specific job factors. Develop an improved method of designing DGAC mixes. Determine the reproducibility of the various laboratory tests selected for the new DGAC mix design procedure. Establish a Statewide formal quality assurance program for asphalt concrete testing and mix design.
Performing Organization: California Department of Transportation, Sacramento, CA 95807
Expected Completion Date: September 1989
Estimated Cost: $223,000 (HP&R)

Title: Cold-Mixed Inplace Recycling of Asphalt Pavements. (FCP No. 44C3184)
Objective: Evaluate by laboratory testing and field experiments the effectiveness of a cold-mixed recycling process as a method for re-using existing bituminous pavement materials.
Performing Organization: New Jersey Department of Transportation
Expected Completion Date: July 1990
Estimated Cost: $43,630 (HP&R)

Title: Mix Design Procedures and Considerations for Polymer Modified Asphalt Compatibility and Stability. (FCP No. 44C5134)
Objective: Define the properties desired in a polymer modified binder. Select or develop tests that will best measure and quantify these properties in materials for seal coats and hot-mixed asphaltic concrete using polymer modified binders. Prepare specifications for modified binders for each application.
Performing Organization: University of Texas, Austin, TX 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: October 1991
Estimated Cost: $325,000 (HP&R)

FCP Category 5—Structural Design and Hydraulics

FCP Project 5A: Bridge Loading and Design Criteria

Title: Static and Fatigue Behavior of Longitudinal Shear Keys in Box Beam Bridges. (FCP No. 45A1232)
Objective: Evaluate the lateral distribution factors, cracking behavior, ultimate load capacity, transverse shear distribution, and fatigue behavior of longitudinally and transversely post-tensioned box beam bridge systems. Method test an acrylic model of bridge cross section. Computer analyze bridge system response. Test half-scale model with cast-in-place slab for static behavior, impact resistance, and fatigue behavior.
Performing Organization: Florida Atlantic University, Boca Raton, FL 33431

Funding Agency: Florida Department of Transportation
Expected Completion Date: August 1987
Estimated Cost: $132,530 (HP&R)

Title: Bent-Column Analysis and Design. (FCP No. 45A1262)
Objective: Prepare a file of bridge bent-column data that can be read by the interactive graphics bent-column program for steel detailing, currently being developed.
Performing Organization: University of Texas, Austin, TX 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1988
Estimated Cost: $55,000 (HP&R)

Title: Design Guide for Short Anchor Bolts. (FCP No. 45A4172)
Objective: Evaluate cast-in-place, short anchor bolts and both mechanical and adhesive retrofit anchor systems for short anchor bolts under static and impact loads. Prepare a design guide and identify applications for short anchor bolts based on this evaluation.
Performing Organization: University of Texas, Austin, TX 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1988
Estimated Cost: $49,500 (HP&R)

FCP Project 5K: Bridge Rehabilitation Technology

Title: Evaluation of the Luling Bridge Retrofit Details Under Service Loads. (FCP No. 45K3272)
Objective: Assess the adequacy of the retrofit procedures developed for the extensive cracking in the main box girder webs of the Luling Bridge by taking strain measurements. Provide data that can be related to the analytical estimates and that will define the service stress range conditions needed. Provide a mechanism to assess other details in the Luling Bridge structure and determine their susceptibility to fatigue crack growth.
Performing Organization: Lehigh University, Bethlehem, PA 18015
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: December 1987
Estimated Cost: $108,000 (HP&R)

FCP Category 9—R&D Management and Coordination

FCP Project 9A: Highway Research and Development Support Activities

Title: Electronic Support Service. (FCP No. 39A1123)
Objective: Provide onsight electronic support services at the Turner-Fairbank Highway Research Center in McLean, Virginia, including design, fabrication, wiring, repair of electronic instrumentation used in the laboratories, and associated electronic support services as requested.
Performing Organization: Halifax Engineering, Inc., Alexandria, VA 22312
Expected Completion Date: October 1989
Estimated Cost: $185,575 (FHWA Administrative Contract)

FCP Category 0—Other New Studies

Title: Chemical Stabilization of Landslides. (FCP No. 40M1000)
Objective: Evaluate chemicals for preventing landslides due to soil creep
Performing Organization: California Department of Transportation, Sacramento, CA 95807
Expected Completion Date: September 1990
Estimated Cost: $213,000 (HP&R)

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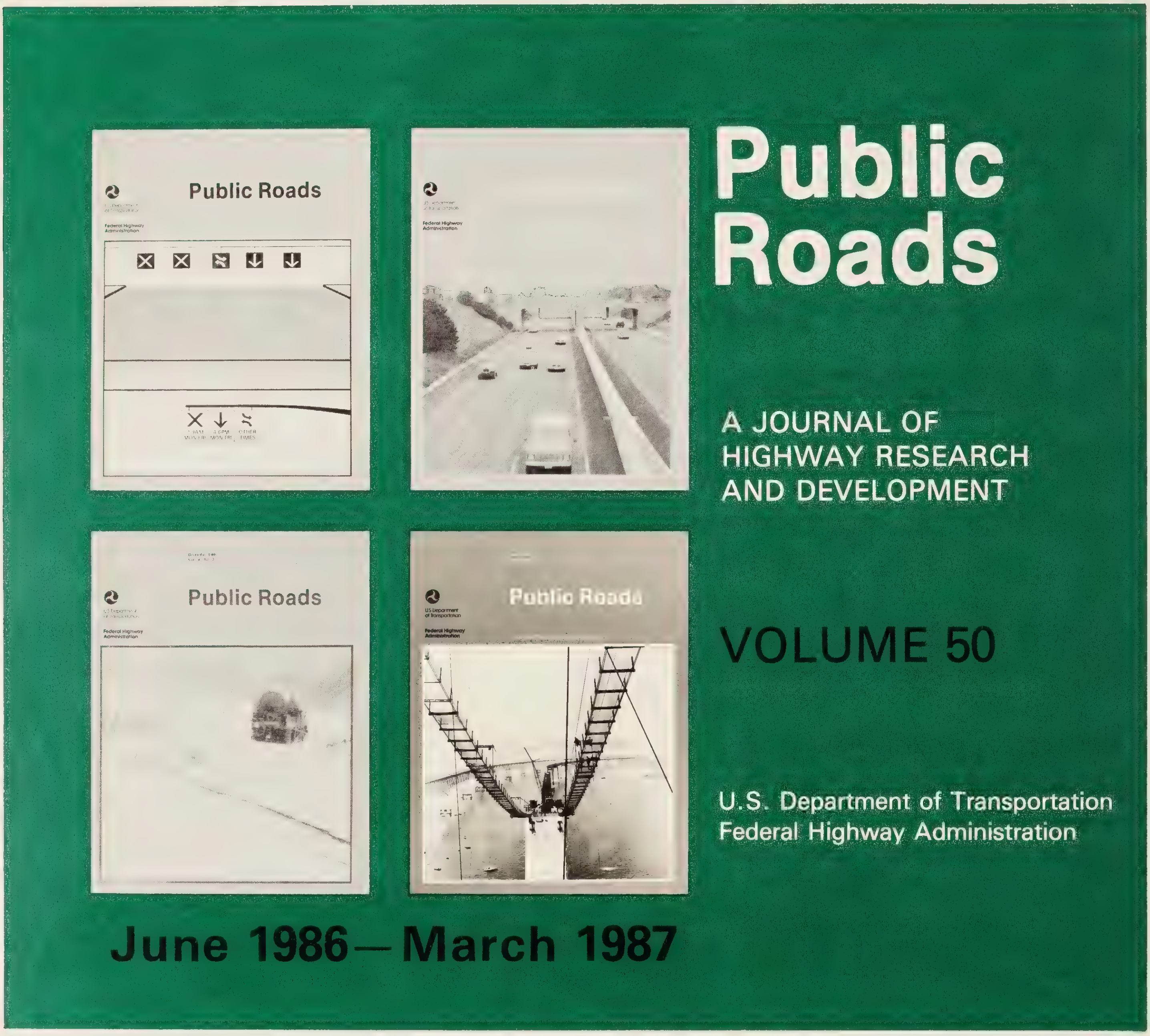

The title sheet for volume 50, June 1986-March 1987, of *Public Roads* is found on the inside back cover of this issue. This sheet contains a chronological list of article titles and an alphabetical list of authors' names.

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