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A Journal of Highway Research and Development

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COVER: Mammoth Scenic Loop in Mono County, California

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Federal Highway Administration
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Federal Highway Administration's Rural Technical Assistance Program

by William L. Williams, P.E.

Introduction

The size of the national system of rural roads is staggering. Eighty-two percent of the our highways are rural; these roads carry 41 percent of the Nation's traffic. All told, there are 3.2 million miles of highways and some 325,000 bridges in rural America. Since thousands of rural communities depend heavily on these vital commercial arteries, the improvement of rural roads and bridges is of utmost national concern.

The Federal Highway Administration's (FHWA's) Rural Technical Assistance Program (RTAP) is a concerted effort to answer this growing concern. RTAP's aim is the economical improvement of rural roads and bridges through a program of training and technical assistance geared to local government officials. Every year since 1981, Congress has appropriated RTAP funds to:

- Increase rural transportation expertise at the State and local levels.

- Promote the effective use of private, local, and State resources for transportation in rural areas.

- Improve roads and bridges in rural areas.

As of June 1989, 45 States and the Commonwealth of Puerto Rico were receiving rural technical assistance services.

Technology Transfer (T^2) Centers

Since 1982, the number of technical projects and subprojects carried out under RTAP has increased from

12 to 87.[1] The largest and most prominent of these projects is the Technology Transfer Program for Local Transportation Agencies. This project created what has now become a national system of T^2 centers.

The objectives of this system are to:

- Establish a mechanism for transferring highway technology to rural transportation officials.

- Improve the flow of technical information among the FHWA, State departments of transportation, universities, and rural transportation officials.

- Encourage the use of new, cost-effective technology by rural transportation officials.

- Test new technology in one center so that it can be quickly used by centers in other States.

Figure 1 indicates the tremendous growth of T^2 centers since 1982, the year in which the first T^2 center agreement was made with Georgia Tech Research Institute. Each subsequent year has seen the addition of approximately 10 new centers. By fall 1986, 42 T^2 centers were in operation.

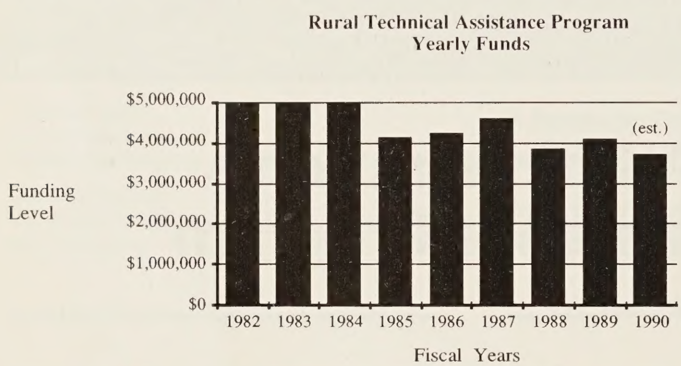

Figure 1.—Growth of technology transfer centers since 1982.

In addition to the centers, a subcenter to translate highway technology into Spanish is located at the University of Texas at El Paso; another small subcenter operates within the U.S. Virgin Islands. At present, six historically black colleges and universities participate in the T^2 center program.

[1] For detailed information on these projects, see the 1989 *RTAP Status Report*, available from the FHWA's Office of Research, Development, and Technology Report Center (703/285-2144).

T^2 Center Operations

As stated, the overall goal of the T^2 center system is to transfer highway technology to the nearly 40,000 local highway agencies across the United States. Although the individual centers operate under the terms of their respective Federal-aid agreements, each is unique and responsible for its own programs. At a minimum, each T^2 center:

- Completes and maintains a comprehensive mailing list of rural officials.

- Publishes a quarterly newsletter.

- Provides local officials with information on new technology.

- Provides a mechanism for the transfer of new technology among States.

- Conducts at least 10 seminars per year for local officials.

- Performs a self-evaluation.

In addition, at least half of the centers conduct selected rural road technical projects.

In all, the centers have conducted 4,864 seminars since 1982—more than twice the number required per center per year—and have taught over 150,800 students.

Additionally, centers carry out a multitude of innovative T^2 activities. Several have traveling vans that take training and technology "on the road" to local officials. Some have traveling engineers to help these officials get the latest know-how firsthand. Many centers have developed "how-to" manuals, technical bulletins, videotape libraries, hot lines, and satellite training classes.

Center Funding

Until 1986, all funding for T^2 centers was provided through Federal RTAP funds. To accommodate the increased demand to start new centers, however, an administrative decision was made that year to reduce Federal funding to 50 percent. (Figure 2 presents annual RTAP fund expenditures.) The State departments of transportation have demonstrated their enthusiastic support of the T^2 concept by providing center funds. (In fact, in FY 1989, six States overmatched the Federal share.) This State support has been supplemented by funds from universities, local users, and State legislators. It is estimated that the total national T^2 expenditure—Federal, State, and local—will approximate $9.5 million to meet the FY 1989 average center budget of $206,522.

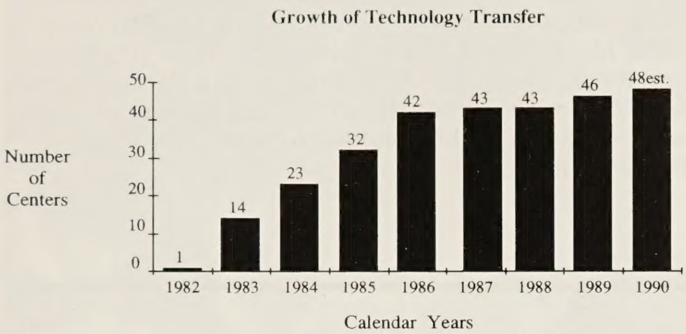

Figure 2.—Rural technical assistance funds, 1982 to 1990.

Does RTAP Pay Off?

Feedback indicates that for every dollar invested by the Federal Government in RTAP, the return on investment is substantial. In fact, direct cost savings resulting from RTAP will exceeded $25 million for FY 1988. It is important to note that many of these savings will repeat again and again in subsequent years. In addition, numerous intangible improvements that result in significant cost avoidance also must be added to these savings. When these are taken into account, total RTAP benefits may exceed $40 million annually.

Some illustrative examples of cost-saving projects implemented under RTAP follow:

• The *State and Local Highway Training and Technology Resources Catalog* was produced and distributed to State training officers and T^2 center directors. The catalog presents information on available training developed by other centers (see figure 3). It is estimated that annual savings in training costs obtained through use of the catalog may average $50,000 per State—or approximately $2.5 million nationally each year.

• The RTAP courses "Maintenance Management System" and "Equipment Management System" have been presented 49 times each. Benefits of the "Maintenance Management System" course include increased crew productivity, improved work methods, increased service levels, and cost savings of 6 to 15 percent in the annual maintenance budget. Benefits of the "Equipment Management System" course include reduced ownership, operating, and maintenance and repair costs, along with a saving of 6 to 13 percent in total equipment costs.

• The Oklahoma T^2 Center prepared the *Geotechnical Fabric on Rural Roads Manual.* Benefits of using geotechnical fabric on gravel roads include reduced maintenance at problem locations, improved level of service, and cost savings of 33 to 67 percent over normal maintenance at problem locations.

• The Pennsylvania T^2 Center developed a videotape on timber bridge fundamentals which was distributed throughout the United States by the FHWA. The videotape highlights Pennsylvania's success with timber bridges. It is conservatively estimated that Pennsylvania is saving over $10 million annually through its application of timber bridge technology.

• The Kentucky T^2 Center developed *When to Pave a Gravel Road.* This useful manual explains in lay terms the steps needed to implement a sound rural road management program and how to choose between alternative paving options. The ability to perform this type of trade-off analysis is important, particularly in light of the fact that two-thirds of the U.S. highway system consist of unpaved or lightly-surfaced low-volume roads. Use of the cost-effective solutions presented can easily save local officials $1,000 per mile. If applied nationally to 15,000 miles of gravel road, projected savings could exceed $15 million each year.

• The decision to recycle involves the use of "life-cycle" costs to determine the least-cost rehabilitation strategy. Studies indicate that recycling techniques can reduce the cost per ton of mix by 25 to 40 percent. A reference manual on training materials was developed, and the training presented as *Pavement Recycling Guidelines for Local Governments.* Available materials include an instructor's manual, student textbook, and a slide kit. These materials have been provided to States and T^2 centers.

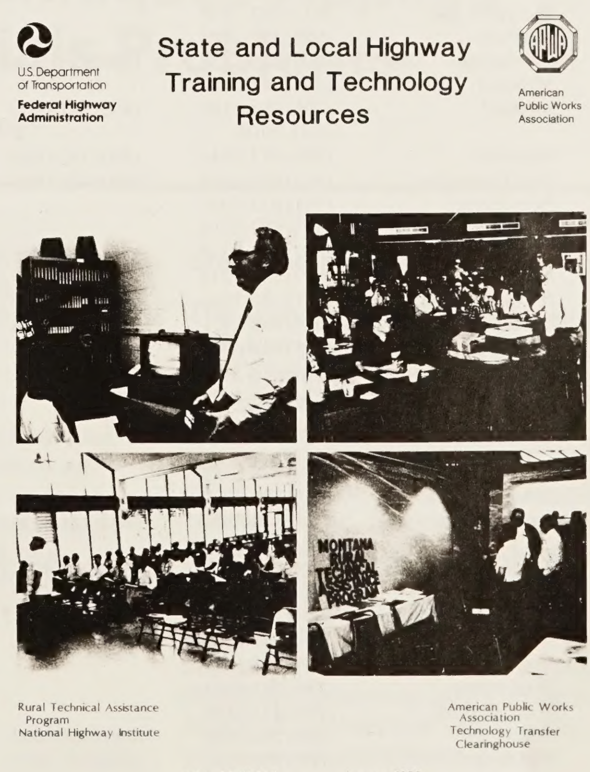

Figure 3.—State and local highway training and technology resources.

The RTAP program is part of the Federal Highway Administration's National Highway Institute. Staff offices are located at the Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, VA 22101-2296 (703) 285-2774. For more information on FHWA's RTAP, contact the T^2 center in your State or the closest FHWA Division Office. Table 1 shows a list of T^2 center telephone, FAX, and electronic bulletin board numbers.

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Table 1.—T^2 center telephone numbers

State	Telephone	In-state Toll Free Number	Fax Number	Electronic Bulletin Board
Alabama	(205) 844-4370		(205) 844-2672	
Alaska	(907) 474-7733		(907) 474-2466	(907) 474-2478
Arizona	(602) 965-2744	(800) 828-7932	(602) 965-8296	(602) 965-1391
Arkansas	(501) 569-2249		(501) 568-1565	
California	(415) 231-9590		(415) 231-9589	(415) 642-7088
Colorado	(303) 491-8648	(800) 262-ROAD		
Connecticut	(203) 486-5400		(203) 486-5381	
Delaware	(302) 736-4570			
Florida	(904) 392-0378		(904) 392-9673	
Georgia	(404) 656-5364		(404) 656-3507	
Idaho	(208) 334-8271			
Indiana	(317) 494-2164	(800) 428-7639	(317) 494-0395	
Iowa	(515) 294-8815			
Kansas	(913) 864-5658		(913) 864-3199	(913) 864-5058 Bitnet KTC @UKCC
Kentucky	(606) 257-4513	(800) 432-0719	(606) 257-3342	
Louisiana	(504) 767-9118		(504) 767-9108	
Maine	(207) 289-2151		(207) 623-1109	
Maryland	(301) 454-2438 4932, 3103		(301) 454-8841	
Massachusetts	(413) 545-2604		(413) 545-0724	
Michigan	(906) 487-2102			(906) 487-2148
Mississippi	(601) 968-2339	(800) 634-4651	(601) 968-2358	
Missouri	(314) 751-0852		(314) 751-6555	
Montana	(406) 994-6100, 6101, 6103	(800) 541-6671		
Nebraska	(402) 472-2844	(800) 332-0265	(402) 472-1901	
New Hampshire	(603) 862-4348	(800) 423-0060		
New Jersey	(201) 932-5074			
New Mexico	(505) 827-5216			
New York	(607) 255-8033		(607) 255-1836	
North Carolina	(919) 787-8233		(919) 783-5656	
N.Dakota/Minn.	(701) 237-7246	(800) 732-2422		
Ohio	(614) 292-2871	(800) 552-6891	(614) 292-9021	
Oklahoma	(405) 744-6049			
Oregon	(503) 378-3421			(503) 373-1321
Pennsylvania	(814) 863-1008		(814) 865-3591 (University Park) (717) 948-6008 (RTAP Office-Capital)	
Puerto Rico	(809) 834-6385			
South Carolina	(803) 656-3000		(803) 656-0124	
South Dakota	(605) 688-5601, 688-5987	(800) 422-0129	(605) 688-5822	
Tennessee	(615) 974-5255	(800) 252-ROAD	(615) 974-8546	
Texas	(409) 845-4369	(800) 824-7303	(409) 845-5726	(409) 845-2326
Utah	(801) 750-2933		(801) 750-3663	
Vermont	(802) 655-2000	(800) 462-6555		
Virginia	(804) 293-1965		(804) 293-1990	
Washington	(206) 753-0143		(206) 753-6218	(206) 586-1942
West Virginia	(304) 293-4550		(304) 293-5024	
Wisconsin	(608) 262-7988	(800) 362-3020	(608) 263-2595	
Wyoming	(307) 766-6743	(800) 231-2815	(307) 766-4444	
T^2 Clearinghouse	(202) 393-2792		(202) 737-9153	

Modern Analytical Techniques Applied to Highway Materials Problems

by W.C. Ormsby

Introduction

The analytical laboratories of the Turner-Fairbank Highway Research Center (TFHRC) are used to address many routine and specialized materials problems. Staff research studies and troubleshooting, as well as round robin testing for new evaluations and specifications for the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO), are conducted in response to highway community needs. This article describes various studies that have been—or are being—performed in response to general or specific needs identified by the States; the FHWA's Regions, Divisions, and operating offices; and other governmental agencies.

Applications

The TFHRC makes use of several different types of laboratory apparatus and procedures to solve problems. (A detailed description of the TFHRC equipment and equipment operating principles was provided in a recent publication.) (*1*)[1]

[1] Italic numbers in parentheses identify references on page 83.

Steel bridge failure analysis

The scanning electron microscope (SEM) and its accessories represent powerful tools for studying the failure mechanisms in failed steel bridges. An illustration of such use was the evaluation of a cracked bridge girder from Maple Heights, Ohio. Specimens from this bridge were submitted for analysis to the TFHRC Structures Division. A thorough laboratory examination of the failed area pinpointed the location of the fracture initiation. Scanning electron microscopy of the fracture surface (figure 1) revealed striations characteristic of fatigue crack growth

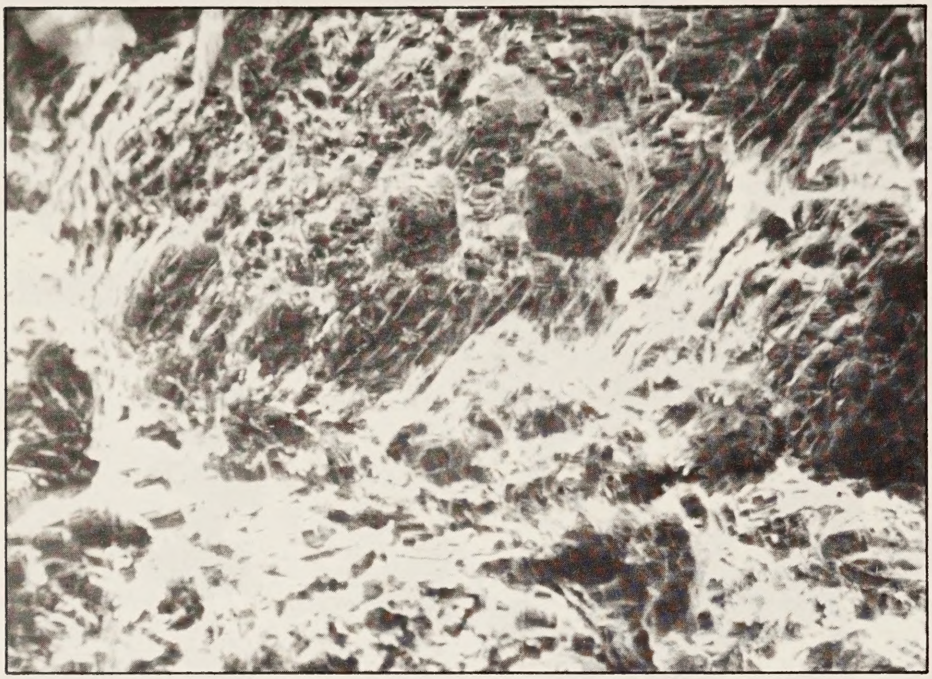


Figure 1.—Scanning electron micrograph of fracture surface of Maple Heights, Ohio, bridge girder.

mechanisms. (*2*) Energy dispersive x-ray fluorescence (EDXRF) analysis of an inclusion, thought to be the source of the fracture, gave a chemical analysis consistent with the nature of the inclusion (presumed to be a weld rod). Details of the evaluation, including a structural analysis, are given by McGogney and Duwadi. (*3*)

Paint analyses

The TFHRC has facilities for formulating and testing bridge and traffic lane marking paints, including thermoplastics. In addition, TFHRC has a bridge inspection kit comprised of such items as thickness gauges, adhesion testers, optical devices, and a sling psychrometer. These instruments are useful in on-site inspections of bridge paint features, such as the following.

Chicamauga Bridge Paint Failure. The Chicamauga Bridge (Tennessee Valley Authority) suffered severe topcoat delamination shortly after painting (figure 2). On-site inspection included measurement of adhesion, paint thickness, and degree of cure. It was determined, by using a "rub test" developed by the FHWA, that the topcoat had been applied improperly over cured inorganic zinc primer. (*4*)

Natchez Trace Bridge Paint Failure. The Natchez Trace Bridge paint failure was studied using both on-site inspection methods and laboratory verification with optical microscopy and EDXRF. It was found that much of the steel was cleaned improperly and did not have the correct surface profile. Paint adjacent to delaminated areas was comprised of five layers (0.015 to 0.020 in [0.381 to 0.508 mm] total thickness) with the primer being of the red lead type (not basic silicochromate as specified [figure 3]). In areas of thinner paint application (0.003 to 0.005 in [0.076 to 0.127 mm]), the primer was basic lead silicochromate as specified; this contains less leachable lead than red lead. Overall, workmanship was poor and specifications were not met with regard to paint composition, surface preparation, and the number of coats applied (no midcoat was applied).

Removal of Lead-Based Paint in Steel Bridge Maintenance. The FHWA was asked to assess the paint compositions on several bridge repainting projects to ascertain if lead containment procedures might be required. These bridges were located in Washington, DC (Ross Drive in Rock Creek Park), Maryland (Patuxent River

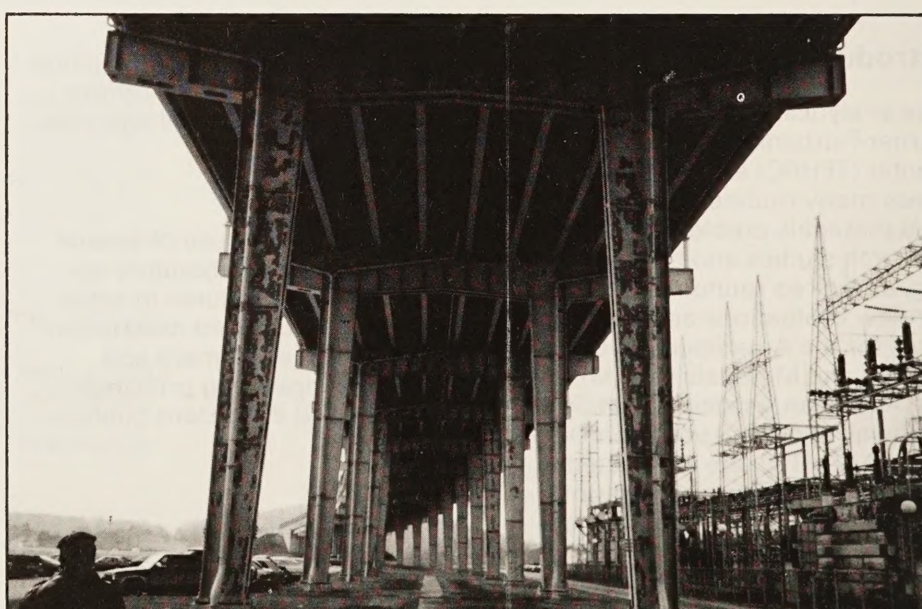


Figure 2.—Chicamauga Bridge paint failure—topcoat delamination.

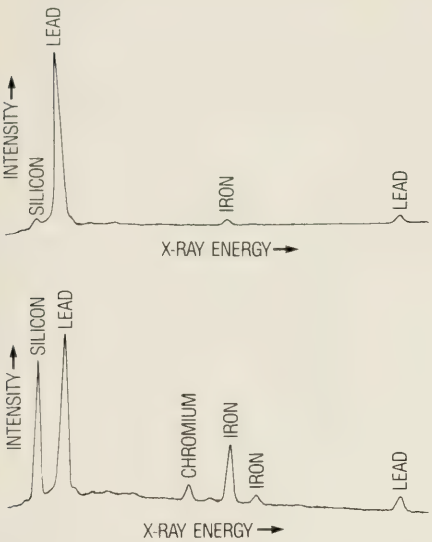


Figure 3.—EDXRF patterns for Natchez Trace Bridge coatings.

Bridge, Baltimore-Washington Parkway), and North Carolina (Linnville Falls Bridge). Based on EDXRF analyses, it was concluded that the Linnville Falls and Rock Creek Bridges had a red lead primer; the Patuxent River Bridge was painted using an iron-oxide-based primer with a topcoat rich in lead (figure 4). These results were reported to the Eastern Direct Federal Division for its use in developing repainting strategies.

Epoxy thermoplastic (ETP) quality control tests

The FHWA sponsored the development of epoxy thermoplastic—a durable, economical, and environmentally acceptable lane marking material. (*5,6*) The FHWA efforts also produced a set of tests and generic specifications for the material. (*7*) A demonstration project was developed around ETP; TFHRC laboratories have provided quality assurance for the materials produced and used in the demonstrations including those reported by the New York State Department of Transportation. (*8,9,10*)

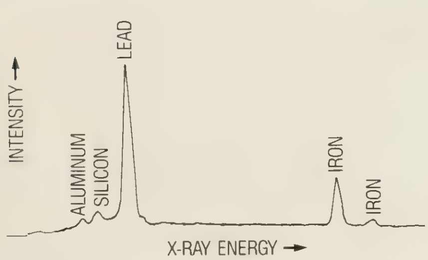
Pavement Binder Materials

Steam distillation of asphalts

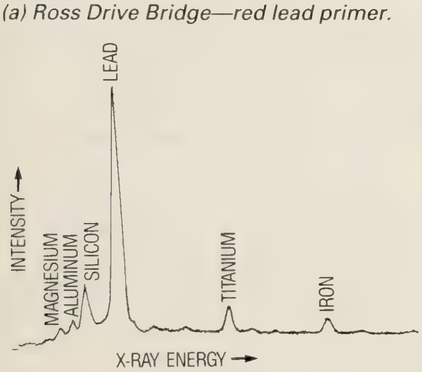
A recent TFHRC paper addressed two controversial points regarding the production of asphalt cement concrete in drum dryers. (*11*)

- Does steam distillation occur in drum-dryer operations?

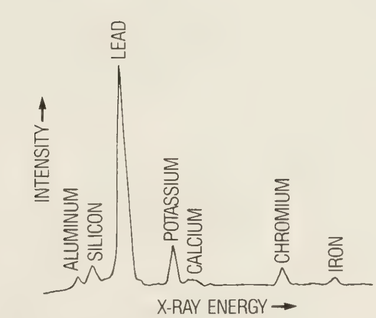
- Are there basic differences between drum-dryer- and pug- mill-processed asphaltic materials?



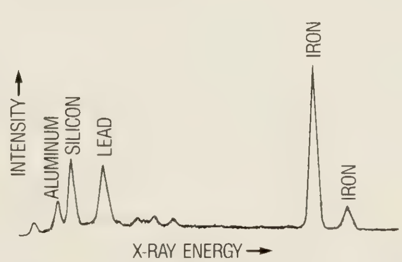
(a) Ross Drive Bridge—red lead primer.



(b) Linnville Falls Bridge—red lead primer.



(c) Patuxent Bridge—red lead topcoat.



(d) Patuxent Bridge—iron-oxide primer.

Figure 4.—Lead content assessment.

To address the first question, numerous virgin asphalts were laboratory-conditioned using various techniques, including steam distillation. Several properties of these asphalts—including physical and thermal properties and molecular size distributions of these asphalts—were compared to those for residues of identical asphalts that had been produced in drum dryers. A statistical comparison of the results for the two sets of asphalts demonstrated that steam distillation does *not* take place in drum-dryer operations.

The question of asphalt changes occurring in drum-dryer versus pug-mill operations was addressed directly by comparing eight "matched pairs"—i.e., pairs of identical asphalts processed separately in both processing operations. Studies of recovered asphalts from all samples suggested that the only difference between the results of the two procedures was that the drum-dryer process caused a slight hardening of asphalts.

Molecular size characteristics versus properties of asphalts

To verify the hypothesis that molecular size parameters of asphalts were related to the thermal cracking properties of pavements incorporating these asphalts, TFHRC staff evaluated possible relationships between asphalt molecular size distributions and asphalt properties. (*12,13*)

Twenty-eight asphalts were characterized by several physical properties, including ductility and limiting stiffness temperature. The molecular size distributions of the asphalts were determined using high-pressure gel permeation chromatography (HPGPC). From HPGPC chromatograms (figure 5), the molecular size distribution and the proportions of large molecular size (LMS) to small molecular size (SMS) molecules were determined.

The asphalt properties and size distributions were statistically compared. The results of these analyses indicate that the molecular size parameters—particularly the LMS contents—do not have a major influence on asphalt physical properties.[2]

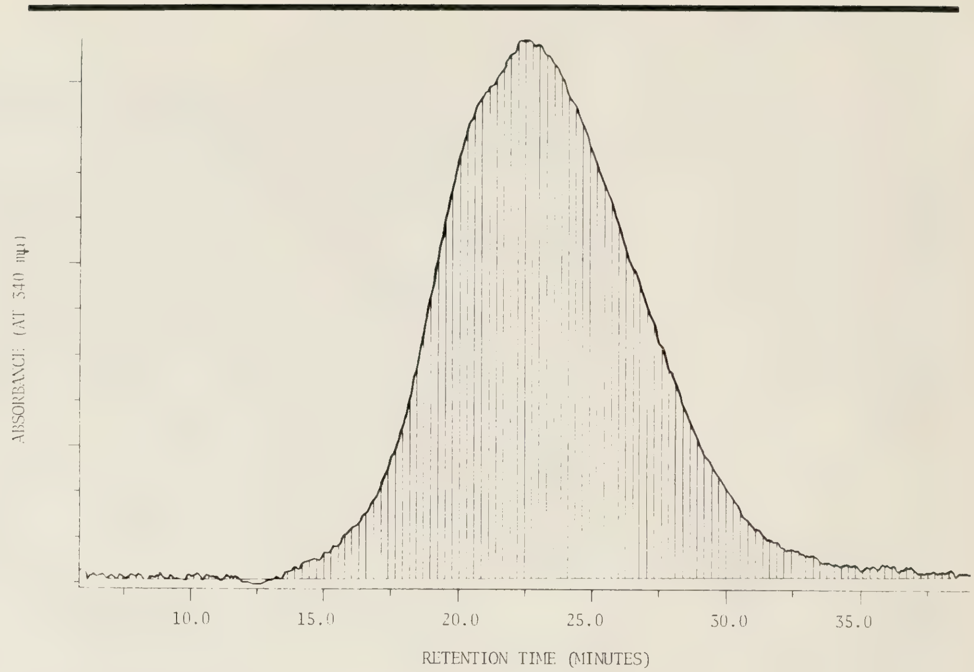


Figure 5.—High-pressure gel permeation chromatogram.

Sulphlex® binder properties and mix design

Sulphlex® is a trade name for a family of pavement binders composed of chemically modified, i.e., "plasticized" sulfur. The FHWA developed these materials during and after the energy crisis of the 1970's so as to have a binder material that could replace asphalt cement, if necessary. Early research on Sulphlex® binders identified a promising binder, Sulphlex® 233, comprised of 70 weight (mass) percent elemental sulfur and 30 weight (mass) percent organic modifiers. This material was extensively field tested during 1980 to 1981; seven full-scale test pavements were constructed. (*14*) To expedite these demonstrations, the FHWA performed a detailed laboratory evaluation of Sulphlex® 233, studying binder properties and developing mix designs. (*15*) Included in these evaluations were physical properties of the binder (e.g., penetration, viscosity [figure 6], specific gravity, solubility, and thin film oven characterization), extractant evaluations, and structural engineering properties of mixes. The need for using anti-strip agents was established.

Sulphlex® 233 performed well in several demonstrations. The material was found, however, to be susceptible to low-temperature cracking. Recent research has identified second-generation Sulphlex®

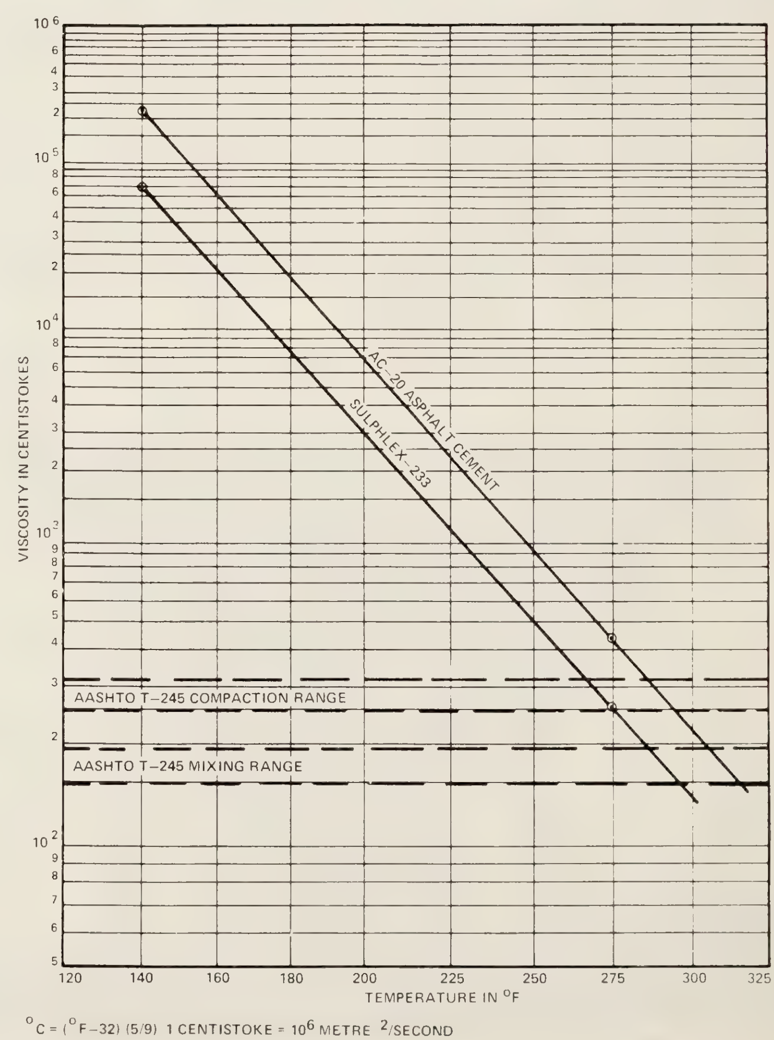


Figure 6.—Viscosity versus temperature— Sulphlex® 233 and AC20 asphalt cement.

[2] Recent statistical analysis of HPGPC data obtained on a much larger asphalt sample population, suggest that significant correlations between asphalt size parameters and asphalt performance exist. See "A Further Statistical Treatment of the Expanded Montana Asphalt Quality Study," *Public Roads*, Vol. 51, No. 3, December 1987, pp. 72-81.

binders that promise to have an acceptable low-temperature behavior. (*16*) In addition, a 10 to 30 ton-per-day (9.1 to 27.2 Mg/d) plant has been designed, built, and tested. (*17*)

The Sulphlex® research program is currently on hold because of the current abundance of oil-derived asphalt, as well as research budgetary constraints. Future work could include pilot plant production and field testing of second-generation binders.

Tests and Specifications

Besides those noted above, several other materials' tests and specifications have been developed in response to the needs of the highway community.

Chloride analysis

The FHWA has a continuing interest in bridge deck problems arising from rebar corrosion. Solutions have been sought through the use of alternative deicers, epoxy coatings for rebars, cathodic protection techniques, and low permeability concretes. To evaluate the efficiency of such techniques or treatments, an accurate and simple method for assessing chloride concentrations is essential. Such a method, developed in the FHWA's staff research program, has been adopted as a standard by AASHTO. (*18, 19*)

Calcium magnesium acetate (CMA) tests and specifications

The FHWA's research program on CMA is in the implementation stage. By combining results obtained through staff research, administrative research contracts, and industrial input, the FHWA has developed a set of tests and specifications for use in CMA quality assurance/quality control. Quality control tests used include: freezing point depression; calcium, magnesium, and acetate contents; mineral impurities; ice melting ability; solubility; density; and pH.

Interest in the CMA program continues to run high, as efforts by other agencies (e.g., New York State Energy Research and Development Authority) are concentrated on lowering the costs of producing CMA. (*20*) Also, under a recent Congressionally mandated study, "Rock Salt Study," an economic analysis of the costs of CMA and rock salt will be made. (*21*)

Latex modifiers for bridge deck overlay concrete

One approach to reducing further chloride ingress and additional corrosion damage to existing bridge decks is to seal the surface with impermeable overlays. One such overlay approach contains latex modifiers as part of the concrete mix. To provide needed guidelines for the use of latex modifiers, the TFHRC thoroughly evaluated various available commercial lattices with respect to physical and chemical properties and chemically fingerprinted them using infrared techniques (figure 7). Latex- modified concretes were studied as to their chemical and physical properties. These studies resulted in the development of specifications, a prequalification program, and a certification program for styrene/butadiene latex modifiers. (*22*) The results have been widely used by State highway agencies.

Other Applications

Samples from Chad, Africa

Two soil samples collected by a representative of the U.S. Agency for International Development in Chad, Africa, were submitted by the Office of Engineering and Operations. The TFHRC staff analyzed and evaluated the samples for their potential in road building.

The first sample was clay-like in appearance—soft, tan, and amorphous. It was comprised of diatoms as shown in figure 8; the EDXRF trace shows that the sample is composed almost entirely of silicon (actually silicon dioxide, SiO_2 [EDXRF does not detect oxygen]). SEM and compositional analysis positively identified the material as diatomaceous earth. The material can be used as a filtration medium in insulating products, a catalyst carrier, a mild abrasive, etc. It has no potential as a highway material.

On a macro scale, the second sample was very well crystallized, the crystals consisting of prisms (figure 9a). On a micro scale, the surface of the crystals exhibited a fine, nodular morphology (figure 9b). EDXRF analysis (figure 9c) shows that the principal component was sodium. Reaction with dilute hydrochloric acid resulted in complete dissolution of the material and release of carbon dioxide. The material was identified as sodium carbonate ($Na_2CO_3 \cdot xH_2O$),

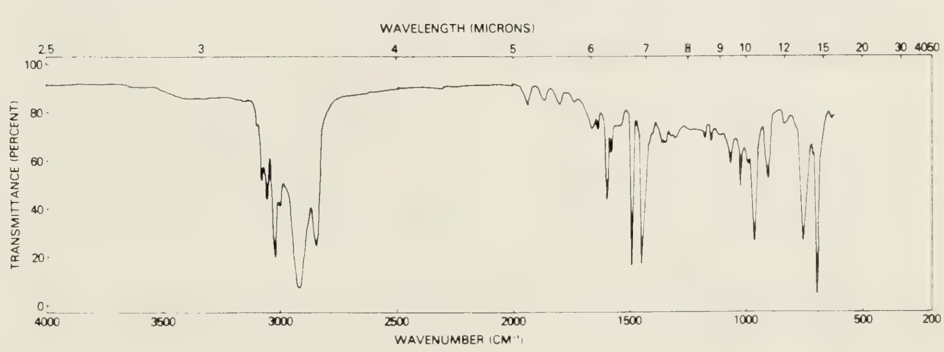
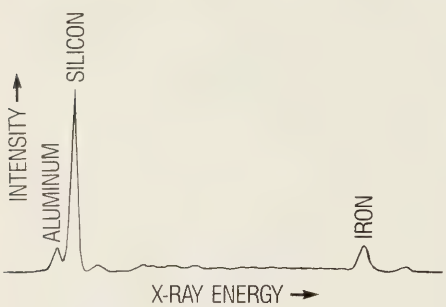


Figure 7.—Infrared spectrum of latex film.

(a) Scanning electron micrograph.



(b) EDXRF spectrum.

Figure 8.—Sample from Chad, Africa.

which can be used in the manufacture of sodium salts, glass, soaps, and as a reagent in producing analytical chemicals. It has no potential for highway use.

Pollutants from abrasive blasting operations of steel bridges

Under a Highway Planning and Research (HP&R) study, the Pennsylvania Department of Transportation is investigating various pollution control strategies for use in the removal of bridge paint. (*23*) The TFHRC's SEM facility analyzes the materials resulting from various surface preparation procedures. The dispersion of pollutants from blasting operations is being monitored using special devices equipped with various types of filters. An example of the appearance of one such filter is given in figure 10a; this sample was collected from a bridge near Chambersburg, Pennsylvania. The SEM shows a 10-micron filter (fibers) which has entrapped several solid particles. EDXRF analysis (figure 10b) reveals large amounts of silicon (silica) from dust and iron (iron oxides) from the bridge. Lead was not detected in the sample tested.

Preliminary results suggest that most of the lead-containing debris is comprised of large particles and is deposited under or near the bridge being blasted.

Summary

The FHWA's materials research programs are designed to solve current or anticipated problems that are affecting or will affect highway operations and maintenance. The examples of problems studied or being addressed have resulted from identified materials needs. These needs are being addressed with a consideration of safety, durability, and environmental acceptability factors. Specifically:

- The epoxy thermoplastics research has successfully produced a more durable, economical, and environmentally acceptable lane marking material.

- The CMA research program has produced an alternative deicer that is efficient, nonpolluting, and noncorrosive.

- The steel bridge painting research program is driven by environmental factors as outlined in the Resource Conservation and Recovery Act of 1976 plus amendments and the amended Clean Air

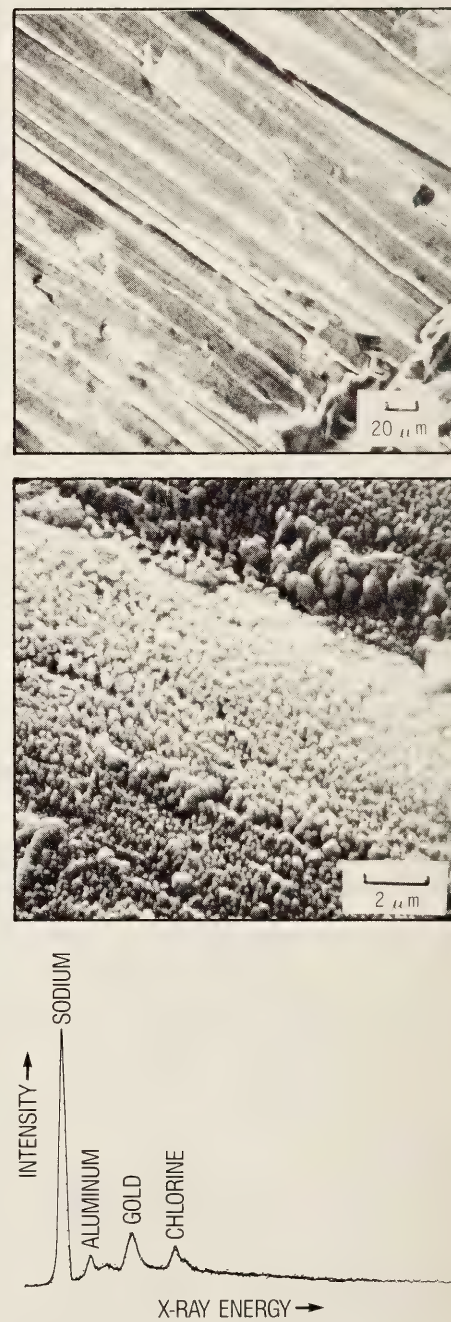


Figure 9.—Scanning electron micrographs 9(a) and 9(b) and EDXRF spectrum 9(c) Sample from Chad, Africa.

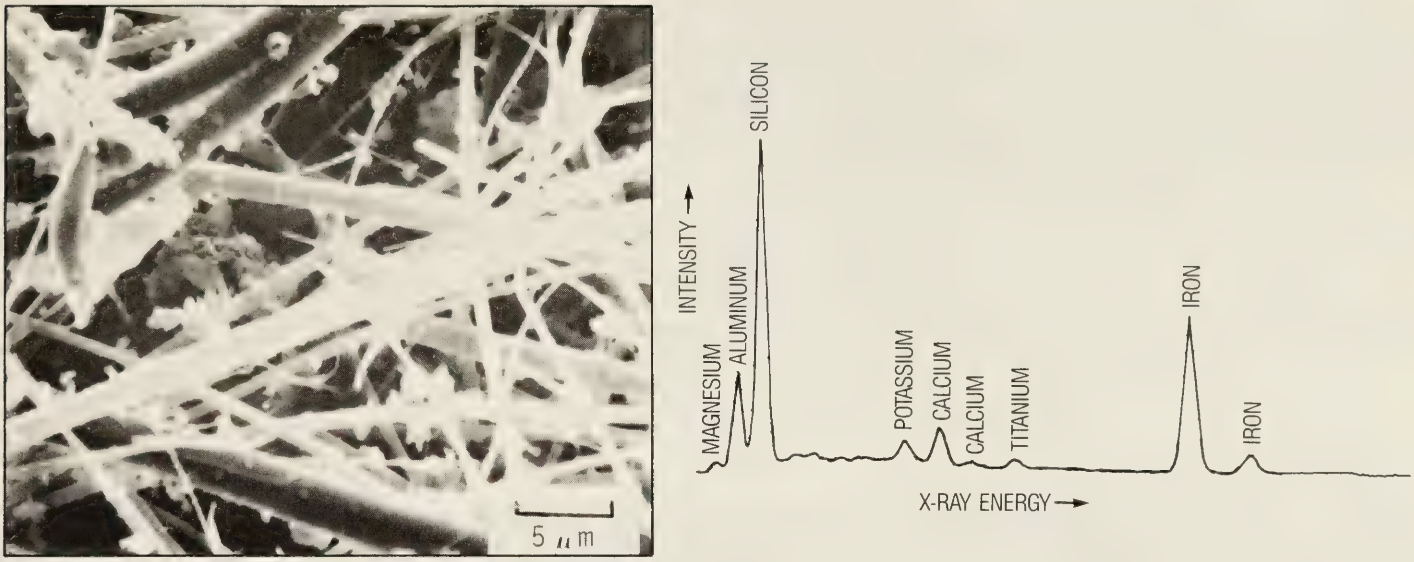


Figure 10.—Scanning electron micrograph 10(a) and EDXRF spectrum 10(b) of debris (10 micron [micrometer] filter) from bridge blasting (Chambersburg, Pennsylvania).

Act of 1970. This program highlights studies designed to develop volatile organic compound (VOC)-compliant bridge coatings and the removal, containment, recovery, and reuse/disposal of paint debris (abrasives, lead components) from bridge repainting operations.

- Materials for improved bridge deck performance, such as latex modifiers for portland cement concrete and epoxy-coated rebars, have been evaluated with particular emphasis on improved durability and safety, bearing in mind the environmental acceptability of new materials and techniques.

Currently, TFHRC is concerned with the electrochemical properties of CMA and asphalt modification (tailoring asphalts). Future staff research will involve studies of VOC-compliant coatings to complement ongoing administrative contract research. Also, plans call for developing an expertise in various Environmental Protection Agency procedures used for analyzing toxic materials in bridge surface preparation and painting operations.

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A Strategic Transportation Research Study for Highway Safety

by Jerry A. Reagan

Introduction

The future of our Nation's highway safety program and the direction of highway safety research and development are currently commanding considerable attention. This attention is vital: The development of a national, measurable highway safety program is an enormous undertaking requiring the creative energies of all those involved. Several recent forums were held for exercising this creativity and assessing the relevant issues. Forums included the following:

- *Campaign "1.5 by 2000." The Automotive Safety Foundation and the Highway Users Federation conducted a strategy session on highway safety priorities in June 1987. The goal of the session was to identify realistic, workable traffic safety measures for the Nation. Based on strategy input from nationally recognized experts concerned about highway safety, the session's sponsors have launched "1.5 by 2000," a campaign to reduce traffic fatalities to 1.5 fatalities by the year 2000 per 100 million vehicle miles traveled (VMT). (1)*[1] In 1988, the fatality rate was 2.4 per 100 million VMT.

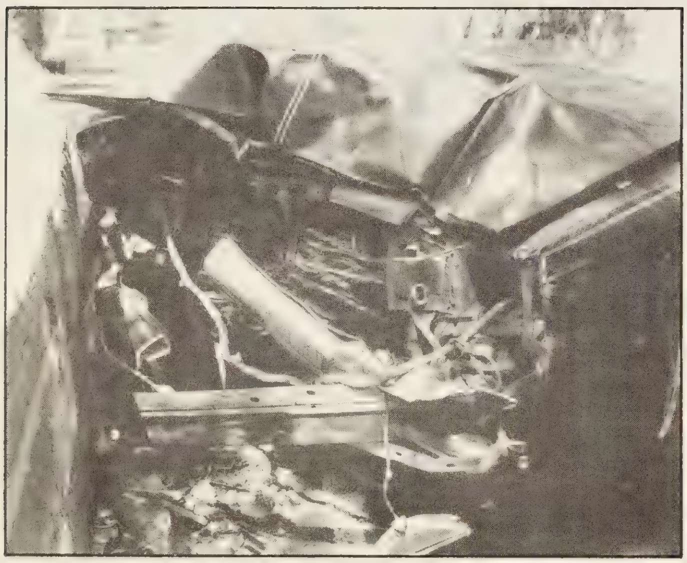
- *"Transportation 2020 Program." In early 1987, the American Association of State Highway and Transportation Officials initiated the "Transportation 2020 Program." The goals of the program are to assess the Nation's surface transportation needs through the year 2020, evaluate alternatives for meeting those needs, and develop national consensus as to the best long-term program with specific, realistic goals and measurable results.*

As part of the "Transportation 2020 Program," 65 public forums were held between August 1987 and May 1988. The participants were largely transportation users voicing their opinions on future highway programs. (*2*)

[1] Italic numbers in parentheses identify references on page 89.

• *"Highway Safety at the Crossroads."* This conference, held in March 1988 by the American Society of Civil Engineers, dealt with specific highway issues related to the roadway environment. (*3*) Conference participants looked at the effectiveness of our highway safety program over the past 20 years, compared it to other national health and safety programs, and presented initiatives to improve highway safety by the year 2010. The conference also addressed political processes and issues in allocating public funds for safety- and nonsafety- related programs.

• *Summer meeting of Committee on Planning and Administration of Transportation Safety. At the 1988 summer meeting of the Transportation Research Board (TRB) committee A1A05, papers were presented in four areas: the driver, the vehicle, the highway environment, and traffic records. Priority issues were identified for each area, and a priority listing was developed based on the combined issues.*



Only one vehicle was involved in 56 percent (25,833) of the fatalities in 1987.

Each of these forums resulted in numerous highway safety recommendations. There was much overlap in these recommendations, particularly in the use of proven technology in such areas as seat belts and alcohol. The forums stressed the need to continue their implementation.

Although the forums identified specific research needs, they did not provide enough data to develop a long-term safety research program. To do this, future research needs must be examined in terms of the "big picture," i.e., the logical constraints that exist today and the technological changes that will exist tomorrow.

What sort of driver-vehicle-roadway interaction will occur in the future? Will technology evolve to the point where a fail-safe roadway environment is possible? Will the crashworthiness of the vehicle increase to the point where traffic barrier systems are no longer needed? What costs are involved? What are their benefits? Who is responsible for the research and subsequent implementation? All of these are issues that must be addressed while developing a national safety program.

In 1987, 44 percent (20,553) of the fatalities involved more than one vehicle.

Start at the Beginning

Every year, much effort and money are spent on major safety initiatives such as driver training and education, improvements to licensing and administrative procedures, increased emphasis on traffic enforcement and adjudication (especially regarding the alcohol-impaired driver), better record keeping and communication regarding the problem driver, and public information and education efforts designed to modify driver behavior. Considerable funds also are devoted to the revision of State motor vehicles laws; vehicle inspection; vehicle design; and highway design, construction, maintenance, and rehabilitation.

In 1987, there were 19,324 fatalities caused by collisions between moving vehicles.

The thrust of these programs is not coincidental. Each deals with some aspect of the basic driver-vehicle-roadway interaction. And it is at this interaction that a new national highway safety program must start.

The Components

The *driver* is a key element in highway safety. It is the driver's responsibility to operate the vehicle in a safe manner. Educating and licensing drivers and enforcing driver compliance with traffic laws are key State responsibilities. How much do these activities affect highway safety? Are they cost effective from a safety standpoint? Are they directed at a known problem? Can human behavior be modified to improve highway safety?

The *motor vehicle* continues to change. Passenger cars are lighter, and more pickups and vans are entering the vehicle fleet. Longer and heavier trucks are using many of the Nation's routes. Passive restraints and antilock brakes are being incorporated into new vehicles; these will improve highway safety. Efforts are being made to increase vehicular crashworthiness. Development of the motor vehicle primarily has been a private sector concern, but there are numerous Federal regulations. Are major safety features being ignored? Are vehicle safety decisions based on cost effectiveness? Is safety a factor in consumer choices?

Strategic Transportation Research Study: Highway Safety Committee

Chairman

Dr. A. Ray Chamberlain
Executive Director, Colorado Department of Highways

Members

Mr. Richard D. Blomberg
President, Dunlap and Associates, Inc.

Dr. Noel C. Bufe
Director, The Traffic Institute
Northwestern University

Dr. John D. Graham
Department of Health Policy and Management
Harvard School of Public Health

Mr. Trevor O. Jones
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Mr. Lester P. Lamm
President, Highways Users Federation for Safety and Mobility

Dr. Lester B. Lave
Professor, Graduate School of Industrial Administration
Carnegie-Mellon University

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Of all fatalities in 1987, 28 percent (12,956) resulted from a collision with a fixed object such as a tree, utility pole, or guardrail.

The *roadway environment* has improved significantly in the past 20 years. Enhancements to edge markings and signing, the removal of roadside obstacles, and the installation of crashworthy guardrails continue. Although State highway agencies have the ultimate responsibility for highway design and construction, the Federal Government is also involved. Is current highway research directed at the critical safety problems? Are highway design features based upon safety data? Are major safety features being ignored because of cost tradeoffs or funding limitations?

In 1987, 16 percent (7,828) of the fatalities involved collisions with people outside the vehicle.

Assessing the Interaction

Accidents represent instances where the system has failed. Consequently, evaluation of driver-vehicle-highway interaction should begin with the analysis of accident data. Accident analysis should be used to identify major problem areas; detailed followup studies will identify causes and, eventually, countermeasures. Unfortunately, the best accident data base—the Fatal Accident Report System (FARS)—only deals with fatalities, and does not contain information on highway geometrics, vehicle volumes, and the like. Thus, the FARS fatality data may not be a good surrogate for all accidents.

In 1987, 11 percent (5,060) of the fatalities resulted from rollovers.

A Study for Highway Safety

The Federal Highway Administration and the National Highway Traffic Safety Administration recently signed a contract with the TRB to conduct a strategic highway safety research study. The study will focus on all aspects of the driver, vehicle, and roadway systems that affect highway safety. Specifically, the study will address these following issues:

- What are today's major highway safety problems, and what will they be tomorrow?

- What existing or new safety initiatives have the highest potential for substantially and cost-effectively reducing deaths and injuries on the Nation's highways?

In 1987, 3 percent (1,604) of the fatalities were caused by collisions with nonfixed objects such as parked vehicles.

Emphasis will be on these topics and areas in which Federal, State, and local governments currently spend their limited resources in efforts to improve highway safety. These current programs will be examined for evidence of their effectiveness. Those judged ineffective will be reexamined to see if they can be improved. The study will then identify problem areas where major capital outlays for intensive research offer the most promise for developing programs that can significantly reduce highway accidents.

The TRB will involve technical experts as well as government and industry leaders, who will review and evaluate the highway safety research needed to define those areas with the highest potential for improving the productivity and/or effectiveness of current safety efforts. They will also evaluate new initiatives that offer substantial promise in reducing deaths and injuries.

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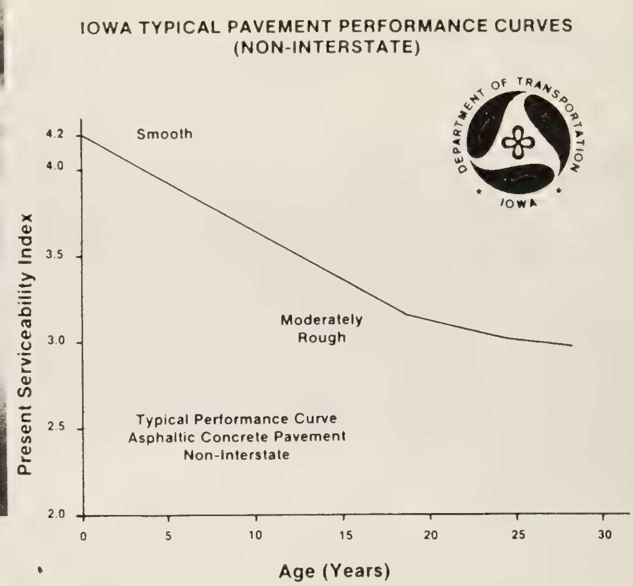
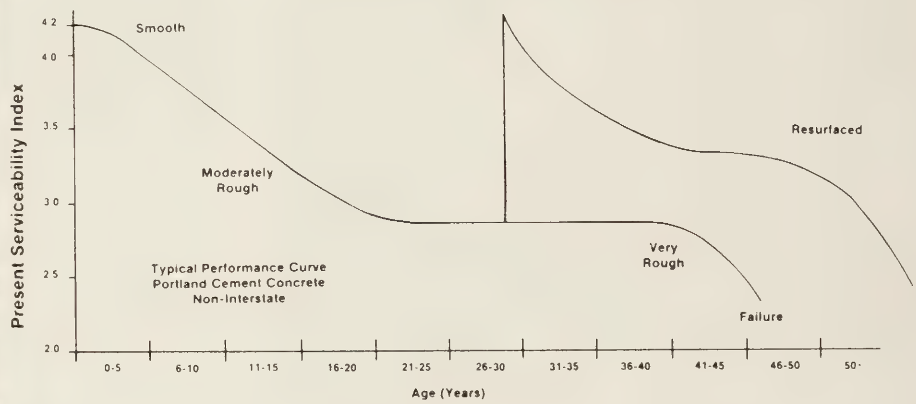
Jerry A. Reagan is chief of the Safety Design Division, Federal Highway Administration (FHWA). Prior to that assignment, he served as chief of the Safety Traffic Implementation Division. Mr. Reagan has had a varied experience with the FHWA. He joined in 1967 as a materials engineer and was later assigned to Region 15 as a soils and foundation engineer. In 1973, he transferred to the Office of Environmental Policy in FHWA headquarters where he worked for 10 years. He first came to the Turner-Fairbank Highway Research Center in 1983 responsible for the National Highway Institute short course program as State Programs Officer.





Pavement Performance Curves: Four Case Studies

by James J. Bednar

Introduction

Three generally accepted measures of pavement performance are safety, functional performance, and structural performance. Each of these, in turn, is indicated by certain component characteristics. Thus:

- *Safety is most commonly measured by the change in the frictional characteristics between the pavement and tires over time.*

- *Functional performance is a measure of how well the pavement serves the user over time and withstands an increasing number of axle load applications. It is most often indicated by ride quality, or roughness; the most widely known is the "serviceability-performance" concept.*

Developed in 1957 by the American Association of State Highway Officials (AASHO) Road Test staff, this concept is the basis for the American Association of State Highway and Transportation Officials (AASHTO) method of pavement design. There are five fundamental assumptions: (*1*)[1]

[1] Italic numbers in parentheses identify references on page 99.

1. Highways are for the comfort and convenience of the traveling public (user).

2. Comfort, or riding quality, is a matter of subjective response or the opinion of the user.

3. Serviceability can be expressed by the mean of the ratings given by all highway users. This is termed the serviceability rating.

4. A pavement has certain physical characteristics which can be measured objectively and related to subjective evaluations. This procedure produces an objective pavement serviceability index (PSI).

5. Performance can be represented by a pavement's serviceability history.

Figure 1 illustrates a typical serviceability-performance curve.

• *Structural performance is a measure of a pavement's physical condition in terms of either its ability to carry additional loads or the occurrence of various distresses such as cracking, faulting, or rutting. Figures 2 and 3 illustrate two typical curves representing a pavement's structural performance.*

Typically, pavement improvement projects are programmed only when particular sections have reached a predetermined minimum acceptable level in terms of either safety, functional performance, or structural integrity. Network pavement management would be greatly improved if engineers could predict with some certainty the rate at which pavement condition is deteriorating. This in turn would help in planning future maintenance, rehabilitation, and reconstruction.

Four States (Arkansas, Iowa, Pennsylvania, and Washington) have recently completed studies to develop pavement performance curves (or equations) based on information currently in their data

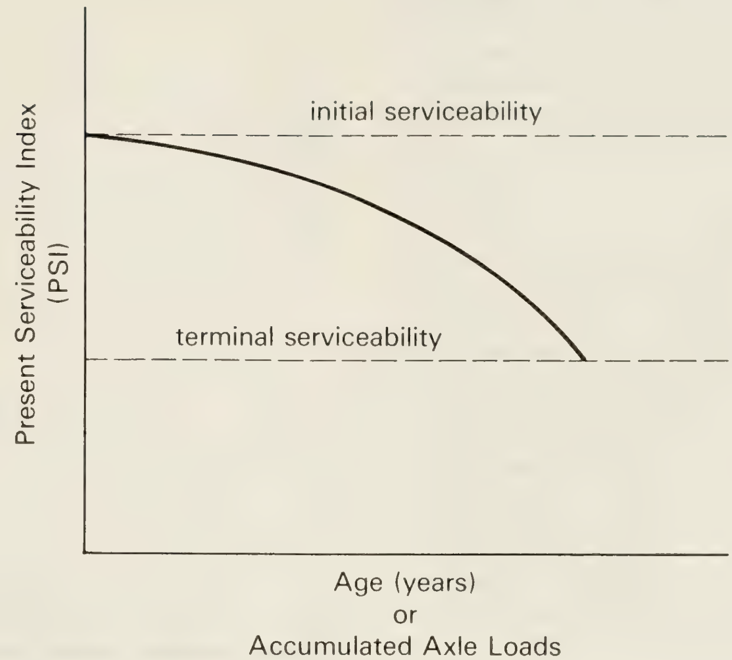


Figure 1.—Typical serviceability-performance curve.

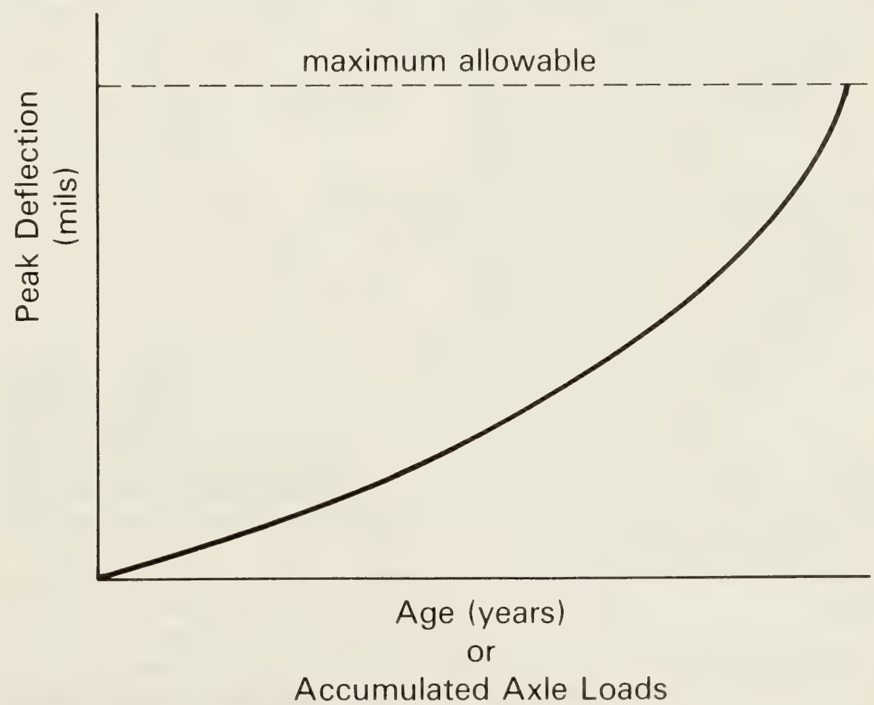


Figure 2.—Typical structural performance curve based on joint faulting.

bases. The States were allowed to use either a functional or structural performance indicator; time was represented either by number of years in service or number of applied equivalent single axle loads (ESAL's).

Arkansas

Arkansas primarily uses its performance data to arrive at an estimated pavement condition rating of a particular section for the current year based on previous surveys of that section.(*2*) Condition ratings contain components for pavement distress and ride; each measured on a scale of 0 to 100. The combined rating is adjusted based on the section's volume of average daily traffic (ADT). The following formula is used to adjust for traffic:

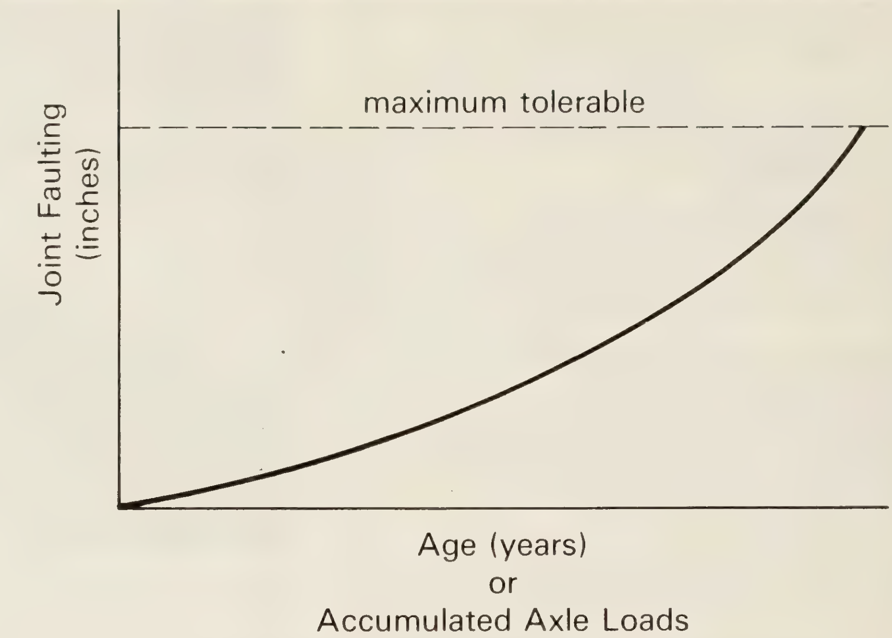


Figure 3.—Typical structural performance curve based on measured deflection.

$$ADJRT = BASRT + \left[\frac{(BASRT)^2 - 100BASRT}{50 \log T_S}\right]\left[\log T - \log T_S\right] \quad (1)$$

Where:

ADJRT = Adjusted pavement condition rating.
BASRT = Basic pavement condition rating.
T = ADT for the rated section.
T_S = ADT standard density.

The adjusted pavement condition rating is plotted on the y–axis; age of pavement is plotted on the x–axis.

Arkansas has developed general curves for its Interstate, primary, and remaining systems based on *all* sections in its data base. System sections are surveyed periodically.

To estimate a section's current condition (when a current survey is not available), the pavement section's current age and corresponding adjusted rating from the general curve is compared to its adjusted rating at the age of the last survey conducted. The difference between the two points is the incremental deterioration predicted since the last survey. If a current survey had been conducted, the value obtained by subtracting this incremental deterioration from the actual adjusted rating at the time of the last survey is the predicted pavement condition rating. Figure 4 is the general plot of adjusted condition rating versus age for the Interstate system.

These curves are incorporated into the department's pavement management program to adjust pavement ratings based upon predicted performance. Since their system is surveyed periodically rather than yearly, this information is of great value.

Arkansas' primary objective in participating in this study was to determine whether plotting adjusted pavement condition rating versus cumulative ESAL's would predict pavement performance more accurately than plots which simply use pavement age. For the analysis, 18 sites—representing a wide range of ADT's, ESAL's, base material, pavement surfaces, and age of pavement—were selected.

Pavement condition ratings were available for these sites from 1980 on. The cumulative ESAL's were calculated by an equation taken from the nomographs used for modeling loading histories for the Strategic Highway Research Program:

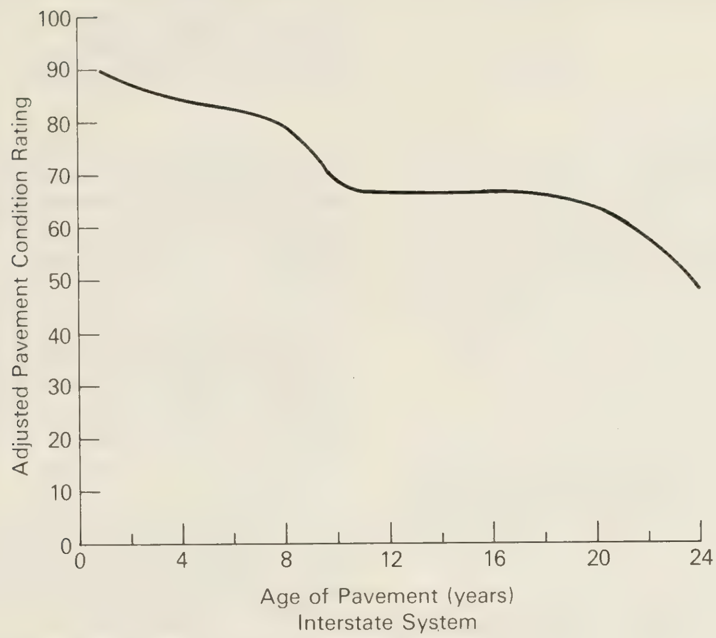


Figure 4.—General performance curve of Arkansas' Interstate system.

$$E = 182.5\ APT\ [\ 1.15 - 0.083\ 1n\ (A/2)]$$

where:

E = ESAL's/Year/Lane
A = Average Annual Daily Traffic (AADT) in two directions
P = Percent Trucks - 100
T = Truck Factor
Rigid Pavement = 1.15
Flexible Pavement = 0.76

(2)

For example, figure 5 is a plot of those portland cement concrete sites which have been rehabilitated since 1980. Similar plots were prepared for overlaid sections and sections which have received no improvements. To test the procedure of plotting the adjusted pavement condition rating versus the cumulative ESAL's, several other sites were identified and plotted. The data fit the curves reasonably well.

Based on this limited analysis, Arkansas concluded that the deterioration curves for its pavement management program should be revised to show pavement condition rating versus cumulative ESAL's. This change will require an improved traffic data base. It also concluded that curves should be further refined based on pavement type, base material, and soil type. As its data base develops, Arkansas will consider developing deterioration curves for each individual pavement management site.

Iowa

The Iowa Department of Transportation (IDOT) had two main objectives in participating in this study.(*3*) One was to demonstrate the development of pavement performance curves using existing traffic and condition data; and the other was to develop specific performance curves for use within the IDOT, especially to incorporate into life-cycle cost analyses.

The State system is divided into four levels of highways. The "A" level consists of only the Interstate routes, the "B" level consists of major U.S. and State routes carrying heavy amounts of traffic, and the "C" and "D" levels provide the transition from State service to the local systems. Pavement performance curves have been developed for the "A" level, "B" level, and the combined "C/D" level.

IDOT measures pavement performance in terms of the PSI, determining this in a manner similar to that used in the AASHO Road Test. Ride is measured using an IJK Roadmeter; the amount of cracking and patching is determined manually by field survey crews. These crews also measure rut depth for both flexible and rigid pavements and faulting of rigid pavement.

Pavement sites were selected based on the four service levels. They were further subdivided by combining sections into construction project lengths and test sections with ages greater than 5 years. Life of each section was determined both by years in service and accumulated 18-kip (80.1 kN) ESAL's. Linear regression techniques were used to develop equations; these included independent variables for thickness, aggregate durability, base, and subgrade characteristics.

The general equations for the Interstate system are as follows (table 1 defines the various factors):

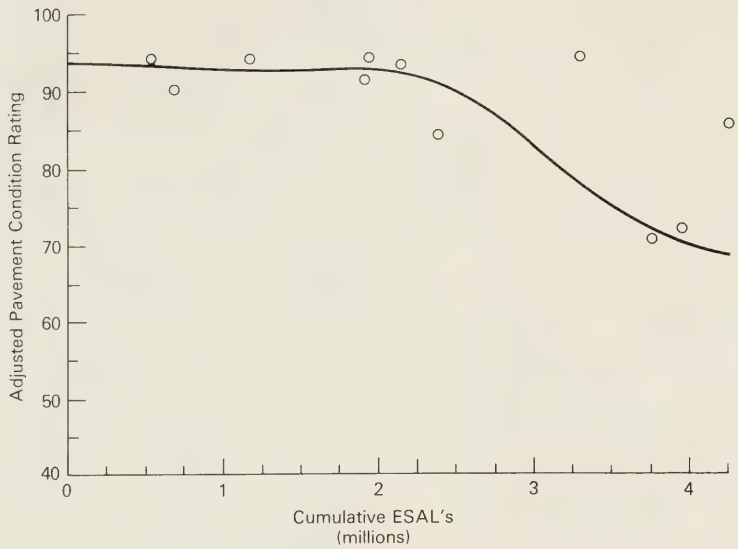


Figure 5.—Performance curve: PCC sites rehabilitated since 1980.

Table 1.—Equation factors for Interstate pavements

PSI:	Present serviceability index
BASE FACTOR:	Effect of the base type –0.31 for ATB (asphalt treated base) –0.10 for CTB (cement treated base) 0.00 for GSB (granular soil base)
DUR:	Effect of aggregate durability –0.27 for durability class 1 –0.06 for durability class 2 0.00 for durability class 3
JOINT:	Effect of joint or reinforcement type –0.08 for joints with aggregate interlock –0.05 for joints with dowels 0.00 for joints with dowels and mesh reinforcement 0.01 for continuously reinforced sections
THICK:	Combined thickness of AC and PCC portions in composite pavements (in inches)
	AC18: Loadings in terms of 18-kip (80.1 kN) equivalent single axle loads 0.0000796 for 8 in (203mm) rigid pavement 0.0000921 for 10 in (254mm) rigid pavement 0.0000984 for composite pavement

Rigid Pavements:
PSI = 4.32 + Base Factor + Aggregate Factor + Joint Factor - Loading Factor (AC18) (3)

Composite Pavements:
PSI = 4.32 + Base Factor + Aggregate Factor + Joint Factor + Thickness Factor - Loading Factor (AC18) (4)

Because of an insufficient number of data points, the following shortcomings could not be eliminated in the modeling procedures.

- Rehabilitation and maintenance effects on the pavement performance were not considered; these are a source of variation in the results.

- Most of the data points of pavement age and loading levels were only partially distributed in each pavement type; this can cause possible bias in the models.

- Initial serviceability index values were assumed to be constant for given designs and surface types. In practice, however, there is variation in the initial product.

- The study only addressed the obvious variables affecting the pavement performance. Many other factors (e.g., climate) also may have an influence.

Aside from the noted shortcomings, data analysis for the Interstate pavements indicates the following performance ranking from highest to lowest PSI combinations:

Base Material	*Aggregate Durability*	*Reinforcement Type*
Granular	Class 3	Continuous
Cement Treated	Class 2	Mesh/Dowel
Asphalt Treated	Class 1	Aggregate Interlock

Individual analysis of the results indicates very little difference in the performance between class 2 and class 3 aggregates and among the continuous, mesh/dowel, and doweled reinforced pavements. The effect of joints on pavement performance is relatively small among types and indicates that some type of load transfer mechanism is needed to aid performance.

For the primary system, levels "B through D" pavements, the performance prediction equations show a strong relationship to pavement age rather than loadings. The general equation for pavements (rigid and composite) at these levels follows (factors are defined in table 2):

PSI = Intercept + Thickness Factor * Total Thickness + Soil Factor + Joint Factor + Soil/Joint Interaction Factor + Age Factor * Age of Underlying Pavement Plus Overlays (5)

The model development for these pavements was subject to the same shortcomings as those for the Interstate pavements.

The analysis of the levels "B through D" pavements indicates

Table 2.—Equation factors for level "B through D" pavements

PSI: Present serviceability index

Variable	Value							
Service Level	B				C & D			
Surface Type	Rigid		Composite		Rigid		Composite	
Age	1	2	1	2	1	2	1	2
1. Total 2. Overlay								
Slope intercept	3.61	3.55	3.61	3.55	3.37	3.71	3.37	3.71
Thickness factor	0.009	0.011	0.005	–0.019	0.044	0.010	0.051	–0.011
Soil factor cohesive	–0.17	–0.02	–0.17	–0.02	–0.07	–0.13	–0.07	–0.13
granular	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Joint factor dowels	0.02	0.06	0.02	0.06	0.03	0.002	0.03	0.002
aggregate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soil/joint cohesive, dowels	0.18	0.02	0.18	0.02	0.12	0.16	0.12	0.16
cohesive, aggregate interlock, granular, dowels granular, aggregate interlock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Age factor	–0.026	–0.026	–0.009	–0.011	–0.026	–0.027	–0.017	–0.032

the following performance ranking from highest to lowest PSI combinations:

Soil	*Reinforcement*	*Soil/Reinforcement*
Granular	Mesh/Dowel	Cohesive/Mesh/Dowel
Cohesive	Aggregate Interlock	Cohesive/Aggregate Interlock
		Granular/Mesh/Dowel
		Granular/Aggregate Interlock

The major variable in this group was soil type: granular was superior to cohesive. This analysis also indicates using granular, drainable bases under all rigid pavements. The effects of thickness and age are greater in the rigid pavement than in the composite section equations. This tends to verify that flexible pavements are influenced most by the underlying soil support and that rigid pavement performance relates more to thickness and the effects of environment.

The equations developed in this study allow IDOT to predict PSI at any given age or loading for different design features. This capability will greatly assist in determining rehabilitation needs and timing and in developing life-cycle cost analyses. Because the equations rely heavily on PSI prediction, future studies should monitor structural performance in terms of surface distress development.

Pennsylvania

The Pennsylvania Department of Transportation (PennDOT) is monitoring 22 pavement sections throughout the State which have been constructed at various times over the last 27 years.(*4*) All of these are reinforced portland cement concrete pavements with a joint spacing of either 61.5 ft (18.75 m) or 46.5 ft (14.17 m).

PennDOT is collecting traffic, PSI, skid, and deflection data for these sections. The traffic data consists of ADT, percent truck traffic, and vehicle classification from which cumulative ESAL's are calculated. The roughness data for determining PSI are collected using a Mays Ride Meter.

Pavement performance curves were generated from the roughness and traffic data for each of the 22 sites using linear regression techniques. PSI's were plotted versus both cumulative traffic and age. (Skid and deflection data were not used in determining pavement performance for this study.) Sites were grouped by joint spacing; an average curve was generated for each group. Figures 6 and 7 illustrate the composite curves for the 61.5 ft (18.75 m) joint spacing for PSI versus ESAL's and PSI versus age, respectively.

The composite curves were compared with information used in the pavement's original design. Results indicate that the quality of the design projections has generally been good. This analysis provides a solid basis from which to project pavement performance in present design work. In addition, the more accurately PennDOT can project pavement performance for various designs, the more improvement it will demonstrate in managing the entire network in terms of life-cycle costs.

Washington

The Washington State Department of Transportation (WSDOT) has had a pavement management system (PMS) in operation for several years.(*5*) Pavement performance curves are used within the PMS program to identify where and when rehabilitation will be needed for each unique pavement section within WSDOT's route system.

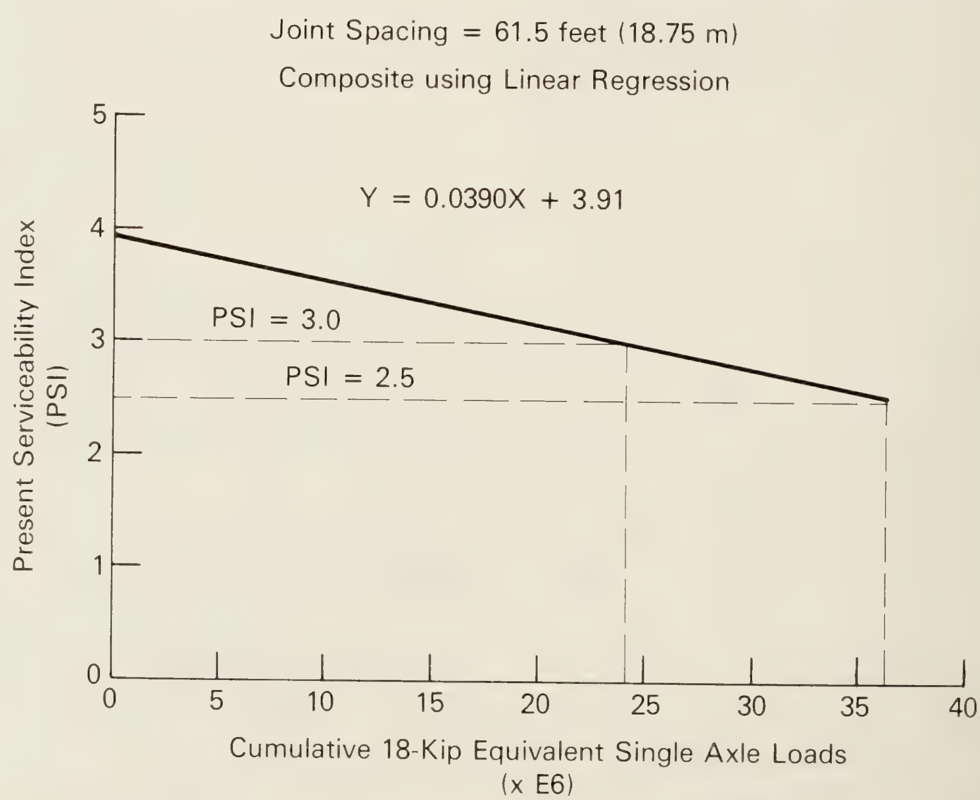


Figure 6.—Serviceability-performance curve for PSI versus cumulative loads.

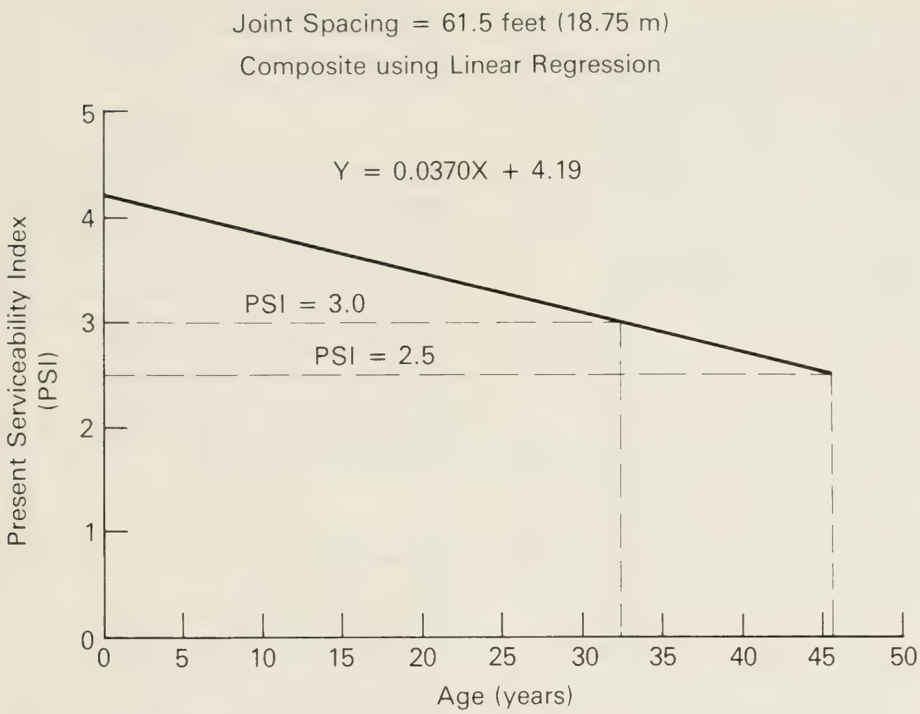


Figure 7.—Serviceability-performance curve for PSI versus age.

WSDOT's measure of performance is a pavement condition rating (PCR) which is a combination of a visual distress rating and a ride rating defined as follows:

$$PCR = [100 - \Sigma D]\ 1.0 - .3 \left[\left[\frac{CPM}{5000} \right]^2 \right] \quad (6)$$

Where: ΣD is the sum of the defect values andCPM is the counts per mile from a Cox Road Rater.

SI conversion: $\frac{CPM}{5000} = \frac{CPk}{3100}$

Where: CPk is the counts per kilometer from a Cox Road Rater.

Table 3 is an example of the weighted defect values for the various deficiencies surveyed on flexible pavements. The PCR may range from 100 (no distress) to below 0 (extensive distress). PCR is largely a measure of fatigue cracking, shown by the relative defect values. Except for the worst conditions, ride input to the equation has little effect.

WSDOT's objective in this study was to develop pavement performance equations for new and rehabilitated pavements to predict more reliably pavement service life and remaining life so that these predictions can be incorporated into life-cycle cost analyses. Their PMS data base was used to develop regression equations for three surface types: bituminous surface treatments (BST), asphalt concrete (AC), and portland cement concrete (PCC).

The primary variables used in this analysis were:

- Pavement condition rating (PCR).
- Age (determined from the time of construction, reconstruction, or overlay to the time of the last PCR).
- Accumulated 18,000-lb (80.1 kN) ESAL (this was estimated for the age of the pavement section).
- Pavement thickness (pavement surface course for either BST, AC, or PCC).

The PMS data base contains 2,616 separate pavement sections determined to have relatively uniform construction and performance. These sections represent over 7,800 centerline miles (12 500 km) of State routes. The total number of sections were separated into eight categories as defined by the first two columns of table 4. The number of sections shown in columns A and B are subsets of the total and represent about 20 percent of the total mileage. These sections were selected for the analysis based on the following two criteria:

- The section performance curve (PCR versus age) was based on actual performance data and had an R^2 value of no less than 0.75.
- The standard error of the performance curve was no larger than 10.

The difference between columns A and B in table 4 is traffic data. Column B reflects the number of pavement sections that have recent traffic and/or vehicle classification counts.

A regression analysis was performed on each data subset, and an associated equation developed. Overall, the one independent variable that was a strong predictor for all regression equations was age. The following trends could be identified based on these equations:

- Bituminous surface treatments and asphalt concrete overlays decrease in PCR about 50 percent faster than new or reconstructed asphalt concrete surface courses.
- Bituminous surface treatments and asphalt concrete overlays decrease in PCR at about the same rate.

Table 3.—Pavement defect values

			Percent of wheel track per station			
			1-24	25-49	50-74	75+
Alligator Cracking	(1) Hairline		20	25	30	35
	(2) Spalling		35	40	45	50 Negative
	(3) Spalling & Pumping		50	55	60	65 Values
				Average width in inches		
				1/8-1/4	1/4+	Spalled
Longitudinal Cracking	Lineal Feet per Station	(1) 1-99		5	15	30
		(2) 100-199		15	30	45 Negative
		(3) 200+		30	45	60 Values
				Average width in inches		
				1/8-1/4	1/4+	Spalled
Transverse Cracking	Number per Station	(1) 1-4		5	10	15
		(2) 5-9		10	15	25 Negative
		(3) 10+		15	20	25 Values
				Average depth in inches		
				0-1/2	1/2-1	1+
Patching	Percent Area per Station	(1) 1-5		10	15	20
		(2) 6-25		15	20	25 Negative
		(3) 26+		20	25	30 Values

SI conversion factor: 1 in = 25.4 mm

Table 4.—Basic pavement categories used for developing general statistics and regression models

Surfacing Type	Construction Type	Column A Number of Pavement Sections (Standard Traffic)	Column B Number of Pavement Sections (Revised Traffic)
Bituminous Surface Treatment	New or Reconstruction	6	2
	Age ≥ 5 Years	5	1
Asphalt Concrete	New or Reconstruction	58	15
	New or Reconstruction Age ≥ 10 years	40	9
	Overlays	383	100
	Overlays Age ≥ 5 years	341	86
Portland Cement Concrete	New or Reconstruction	31	3
	New or Reconstruction Age ≥ 15 years	29	3

- New or reconstructed asphalt concrete surfaces decrease in PCR about 150 to 200 percent faster than new or reconstructed portland cement concrete.

The validity of these trends depends on the degree to which pavement sections used in developing the regression equations are representative of the entire WSDOT system. Figure 8 illustrates how PCR changes with age for the four pavement surface types analyzed. This information is useful for predicting pavement service life and remaining life for life-cycle cost analyses.

Summary

These preceding case studies show that there are many ways to define and measure pavement performance. The key to effective pavement management is not so much *how* performance is determined, but rather the *commitment* to monitor network performance, in whatever terms have been selected. As the period of time over which pavements are monitored increases, so does the confidence level of predicting future performance based on past experience. This aids greatly in the long-term planning, design, construction, and maintenance of our highway system.

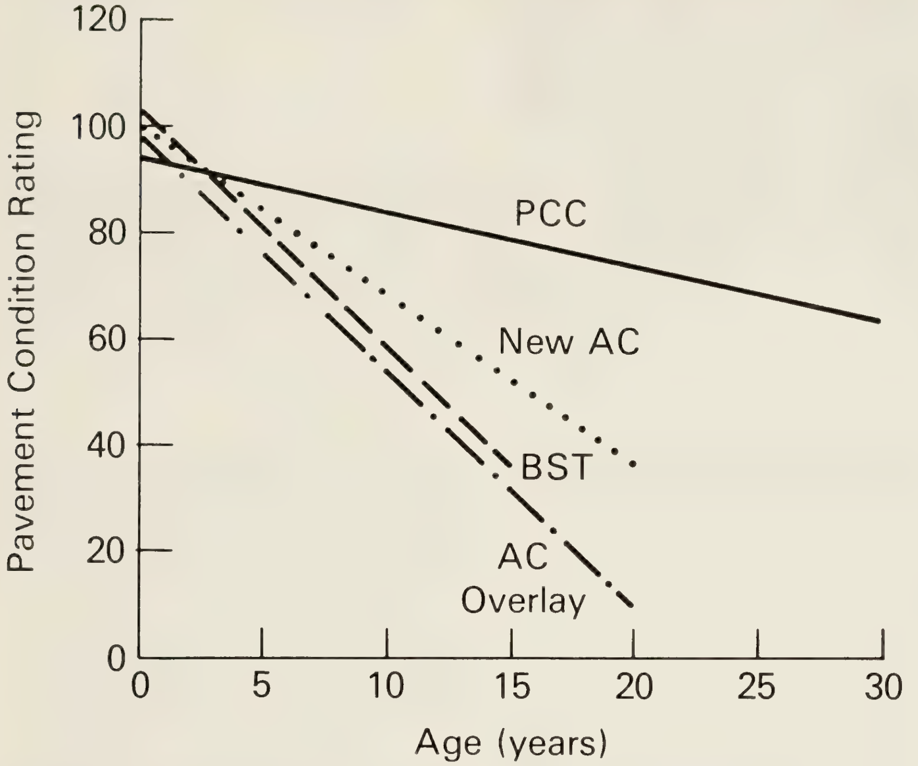


Figure 8.—Pavement condition rating versus age for various pavement types.

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References

(*1*) R. Haas and W.R. Hudson. *Pavement Management Systems,* Krieger Publishing Company, Malabor, FL, 1982.

(*2*) "Study of Pavement Performance Curves," Arkansas State Highway and Transportation Department, Little Rock, AR, October 1988.

(3) "Pavement Performance Curves—Pavement Performance Prediction," Iowa Department of Transportation, Ames, IA, April 1988.

(*4*) "Pavement Performance Curves," Pennsylvania Department of Transportation, Harrisburg, PA, September 1989.

(5) "Pavement Performance Equations," Washington State Department of Transportation, Final Report, Olympia, WA, March 1988.

Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Office 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. All reports are available from the National Technical Information Service (NTIS). In some cases limited copies of reports are available from the RD&T Report Center.

When ordering from the NTIS, include the PB number (or the report number) and the report title. Address requests to:

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

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

Variable Speed Limit System Cost Benefit Analysis, Publication No. FHWA-RD-89-004

by Safety Traffic Research Division

The variable speed limit (VSL) system displays both the maximum and minimum speeds based on traffic and environmental conditions. In addition, brief driver information messages can be displayed to warn of traffic conditions ahead. The VSL system can operate independently (isolated), in a series of stations (linked), as a component of a larger management system (integrated), and, in the future, as part of a system to provide all types of driver information (in-vehicle).

This analysis compares the four types of VSL systems to the existing "fixed" speed limit system. VSL costs include equipment (installation and maintenance), accident-induced delay costs, and time costs. A number of assumptions are made relating to projected accident rates, traverse time costs, and drivers' responses to the system.

The model, using Lotus 1-2-3, calculates the cost and benefits for the set of roadway, traffic, and weather conditions entered by the user. Four scenarios were run, one for each of the VSL types using actual site information. The benefit-cost ratios computed were 37 to 1 for the isolated system, 22 to 1 for the linked system, 55 to 1 for the integrated system, and 53 to 1 for the in-vehicle. These ratios are very sensitive to the assumptions made where actual data were not available.

This publication may only be purchased from the NTIS. (PB No. 89-229603/AS, Price code: A03.)

Highway Safety Research, Development, and Technology Transfer Program, Publication No. FHWA-RD-89-080

by Safety Design Division

In 1988, the Federal Highway Administration initiated a study to define the future highway research, development, and technology transfer (RD&T^2) program. The authors met on two occasions to present their views, and to attempt to consolidate the group's thinking into a consensus report.

This report discusses a broad research, development, and technology transfer program with a goal to reduce fatalities, injuries, and accident costs by 25 percent. The estimated cost of the RD&T^2 program is $150 million annually. Two of the participants presented minority views that are included in the report.

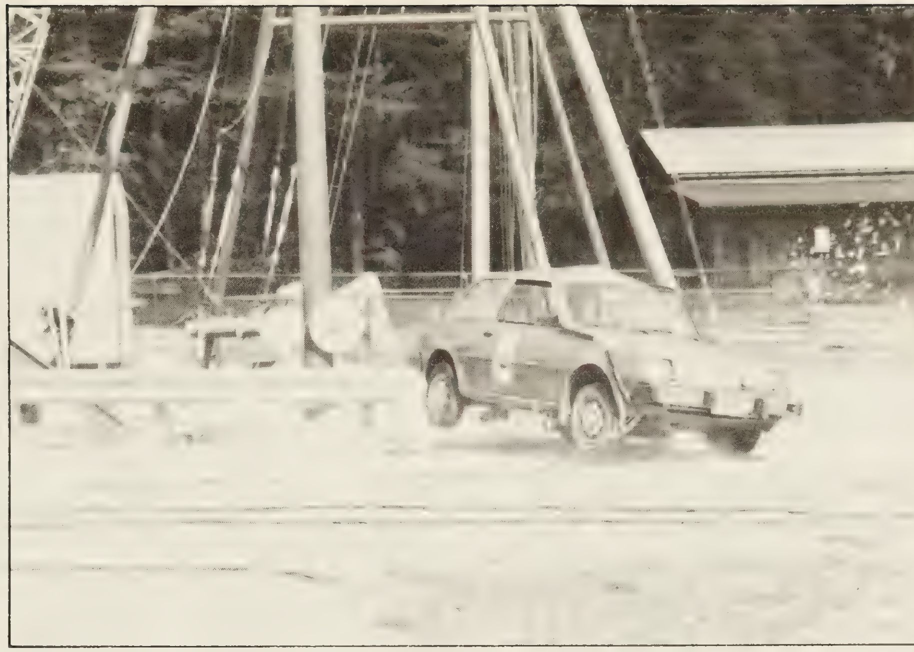
This publication may only be purchased from the NTIS. (PB No. 89-210983/AS, Price code: A04.)

Thirty Mi/H Broadside Impact of a Minisized Vehicle and a Breakaway Luminaire Support, Publication Nos. FHWA-RD-89-089 through FHWA-RD-89-096

by Safety Design Division

These reports document the full-scale side impact testing into a breakaway luminaire support. The test vehicles were a 1980 Plymouth Champ, a 1981 Plymouth Champ, and a 1980 Dodge Colt. The impact speed was 30 mi/h (48.3 km/h); the impact angle was broadside; and the impact point, unless noted, was aligned near or at the driver's shoulder. Except for one test, the luminaire support used was a slip-based-mounted steel unit with a mast arm and luminaire. A side impact dummy (SID) was used for all tests.

FHWA-RD-89-089(1980 Plymouth Champ)Although the luminaire support broke away with a slight change in vehicle velocity, its intrusion into the passenger compartment would cause a severe accident. Most dummy related parameters produced outputs which exceeded the recommended levels. (PB No. 89-214571/AS, Price code: A04.)



FHWA-RD-89-090(Dodge Colt)In this test the luminaire support was mounted on a Union Metal Transformer base rather than attached to a slip base. Upon impact, the luminaire support crushed into the vehicle as it slowed. The vehicle then began to yaw and finally stopped after it spun around about 150 degrees. Because the luminaire support did not break away, there was extreme penetration in the occupant compartment. All dummy parameters exceeded the acceptable thresholds. This would have been a fatal accident. (PB No. 89-214589/AS, Price code: A04.)

FHWA-RD-89-091(Dodge Colt)Although the luminaire support broke away with a slight change in vehicle velocity, intrusion of the luminaire support into the passenger compartment would cause a severe accident. Dummy related parameters produced outputs which exceeded the recommended levels. (PB No. 89-214597/AS, Price code: A05.)

FHWA-RD-89-092(1980 Plymouth Champ)Although the luminaire support broke away with a slight change in vehicle velocity, violent intrusion of the luminaire support into the passenger compartment would cause a severe accident. The luminaire support intrusion caused the door to spring open, did not result in dummy ejection, but resulted in very high dummy parameters. (PB No. 89-214605/AS, Price code: A05.)

FHWA-RD-89-093(1981 Plymouth Champ)The impact point was aligned 12 in (304.8 mm) behind the driver's shoulder. Although the luminaire support broke away with a slight change in vehicle velocity, violent intrusion of the luminaire support into the passenger compartment would cause a severe accident. The luminaire support intrusion caused the door to come open which allowed the dummy to be ejected. Dummy parameters were all very high. (PB No. 89-214613/AS, Price code: A05.)

FHWA-RD-89-094(1980 Plymouth Champ)The impact point was aligned 12 in (304.8 mm) forward of the driver's shoulder. The luminaire support did not break away which caused the vehicle to stop abruptly and wrap around the luminaire support. Vehicle intrusion into the passenger compartment was severe. Dummy parameters were moderate. (PB No. 89-214621/AS, Price code: A05.)

FHWA-RD-89-095(Dodge Colt)The impact point was aligned 24 in (609.6 mm) forward of the driver's shoulder. The luminaire support broke away with a slight change in vehicle velocity, with some intrusion of the luminaire support into the passenger compartment. Dummy parameters were all low. (PB No. 89-214639/AS, Price code: A05.)

FHWA-RD-89-096(1981 Plymouth Champ)The slip base was fastened together with no clamp load. The luminaire support broke away with low change in velocity of the vehicle and with some intrusion of the luminaire support into the passenger compartment. The crush was approximately half of that observed with clamped, slip-base luminaire supports. Dummy parameters were moderate. (PB No. 89-214647/AS, Price code: A04.)

These publications may only be purchased from the NTIS. A paper on this research was presented at the Society of Automotive Engineer's (SAE) 1989 International Congress and Exposition in Detroit, Michigan. The paper, "A Summary of Recent Side Impact Research Conducted by the Federal Highway Administration," No. 890377, is available in SAE Publication No. SP769, "Side Impact: Injury Causation and Occupant Protection."

A final report on this research, Publication No. FHWA-RD-89-157 Side Impact Research, Vol. I: Technical Report is in its final stages. It will be published in 1990.

Motorist Compliance with Standard Traffic Control Devices, Publication No. FHWA-RD-89-103

by Traffic Safety Research Division

This report describes a study of motorist compliance with standard traffic control devices. The research included a comprehensive review of past studies; contacts with traffic, law enforcement, and department of motor vehicles personnel; and an assessment of the viability of other information - sources to identify and quantify motorist compliance. While there is considerable concern about motorist noncompliance, little data existed to determine the frequency or consequences of the problem. Motorists—both typical and those having high violation rates—were interviewed to determine the reasons for noncompliance. Compliance is generally a function of perceived reasonableness of the traffic controls. Therefore, field studies to observe motorist behavior were conducted to establish the extent of noncompliance. Six noncompliance problems were selected and data were gathered at over 900 sites in four States. The results indicate that, although noncompliance is not uncommon (e.g. not making a full stop at a STOP sign), the occurrence of conflicts resulting from it is insignificant.

Potential countermeasures for increasing compliance were identified with the assistance of a panel of highway safety experts. Before/after field studies were conducted to evaluate several of the potential

countermeasures that involved engineering changes. Limited changes in compliance were observed.

This publication may only be purchased from the NTIS. (PB No. 89-194831/AS, Price code: A08.)

Progression Through a Series of Intersections With Traffic Actuated Controllers, Vol. I: Technical Report, Publication No. FHWA-RD-89-132; Vol. II: Users Guide, Publication No. FHWA-RD-89-133

by Traffic Systems Division

Many traffic control systems on urban arterials and grid networks include signals with actuated controllers. However, the computer programs cannot optimize the timing of coordinated actuated signals. Users have to apply techniques designed for pretimed signals, and then "translate" the optimized pretimed settings into settings for the actuated controllers. In addition, other signal control choices, such as whether to operate a particular signal as pretimed, semi-actuated, or fully-actuated, are left entirely to the user.

Volume I describes the development of procedures for applying the MAXBAND, PASSER-II and TRANSYT-7F timing programs to systems with actuated controllers. The results from the testing of the procedures on 14 representative grid systems and arterials with the NETSIM simulation model are presented. This report also describes the development and testing of criteria for selecting the type of signal control at specific intersections for commonly occurring field conditions.

Volume II is a Users Guide for applying MAXBAND, PASSER-II and TRANSYT-7F timing programs to systems with actuated controllers. Guidelines on how to select the type of signal control at specific intersections for commonly occurring field conditions also are presented. The guidelines are based on operating strategies developed for 14 representative grid systems and arterials and tested through simulation with the NETSIM program.

These publications may be purchased from the NTIS. Vol. I (PB No. 89-195341/AS, Price code: A07); Vol. II (PB No. 89-195358/AS, Price code: A03.) They also may be obtained from the McTrans Center, University of Florida, Gainsville, FL.

GRAFIN-GRAFIX Interactive Program, Publication No. FHWA-RD-89-176

by Safety Design Division

The GRAFIX INteractive (GRAFIN) program has been developed to make the old GRAFIX post-processing program easier to use. The GRAFIN program allows the user to display graphic output from Federal Highway Administration computer simulation programs. The program queries the user for appropriate vehicle, barrier, and terrain information, and gathers and manages all necessary files for graphic output production. The GRAFIN program is structured in two main parts; a front-end portion to manage program files, and a modified version of the old GRAFIX program. The report is a stand-alone manual for the GRAFIN program and an addendum to the old GRAFIX manual.

This publication may only be purchased from the NTIS. (PB No. 89-232136/AS, Price code: A08.)

INPREP—Interactive Plotting and Reporting Program, Publication No. FHWA-RD-89-177

by Safety Design Division

The INteractive Plotting and REporting Program (INPREP) has been developed to make the old PREP post-processing program easier to use. INPREP is a menu-driven program that allows the user to produce time history plots and generate output reports for Federal Highway Administration computer simulation programs. This report is a stand-alone manual for the INPREP program and is an addendum to the old PREP manual.

This publication may only be purchased from the NTIS. (PB No. 89-232144/AS, Price code: A04.)

GUARD Version 3.1 Users and Programmers Manual, Publication No. FHWA-RD-89-178

by Safety Design Division

This report is a users and a programmers manual to the GUARD computer program. By using this report, a potential user of the GUARD program would better understand the program requirements, program formulation, execution procedures, and applications of the GUARD program. This manual incorporates changes that were made to the previous GUARD version 3.0 program and presents them as the updates to GUARD version 3.1.

GUARD is a finite element computer code used to simulate the interaction of a vehicle with a roadside device (i.e., guardrail) and the road surface itself. GUARD is capable of simulating a number of roadside devices and a number of different vehicle characteristics. The vehicle is modeled as a three-dimensional lumped parameter body, while the barrier (roadside device) is modeled as a three-dimensional object represented by displacement finite elements. The vehicle/barrier interaction is modeled by geometrically determining the interference between the two surfaces.

Modifications made to GUARD version 3.0 have been incorporated into this new GUARD version 3.1. Modifications include changes in data structure and format of data input, input echo, vehicle output, barrier output, onscreen simulation messages, and a new terrain input structure.

This publication may only be purchased from the NTIS. (PB No. 89-232151/AS, Price code: A20.)

Numerical Analysis of Roadside Design (NARD) Version 2.0, Vol. I: Users Manual, Publication No. FHWA-RD-89-179; Vol. II: Programmers Manual Publication No. FHWA-RD-89-180; Vol. III: Engineering Manual, Publication No. FHWA-RD-89-181

by Safety Design Division

NARD 2.0 is a finite element code with the capability of simulating vehicle dynamics and maneuvering, and vehicle crashes with roadside objects. The vehicle is modeled as a three-dimensional lumped parameter articulated body with multiple units. The barrier is modeled as a three-dimensional object represented by displacement finite elements. Large deflections and rotations are accommodated in the program through nonlinear material behavior. The vehicle/barrier interaction is modeled by geometrically determining the interference between the two surfaces.

The new NARD 2.0 code resulted from extensive revisions and modifications of an original NARD code. Modifications include changes in data structure and format for data input, input echo, vehicle output, barrier output and onscreen simulation messages. They also provide a new three dimensional terrain algorithm, skid velocity option, user supplied contact section ability, and improved current post-soil interaction algorithm.

These publications may only be purchased from the NTIS. Vol. I (PB No. 89-232177/AS, Price code: A12); Vol. II (PB No. 89-232185/AS, Price code: A13); Vol. III (PB No. 89-232193/AS, Price code: A05.)

Requirement for Traffic Assignment Models for Routing Drivers With In-Vehicle Guidance Systems, Publication No. FHWA-RD-89-182

by Traffic Systems Division

This report describes the requirements that a traffic assignment model must satisfy in order to be used as a part of an in-vehicle guidance system. In such a system, the model would be used to develop optimal routes for each driver. Routing instructions would then be conveyed to the driver through the medium of an in-vehicle guidance system.

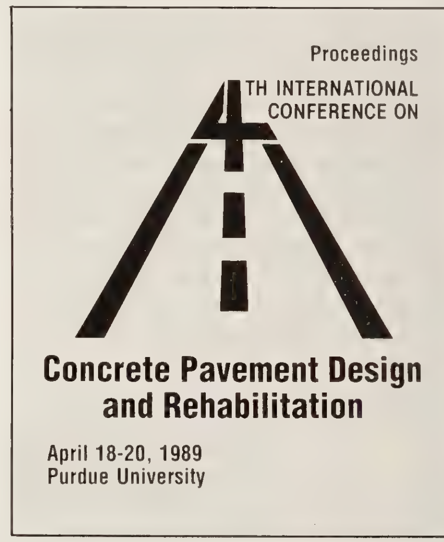
Two generic traffic assignment models, the equilibrium and incremental models, and their application to the optimal routing problem are described. It is indicated that further research is needed in several areas if these models are to be used for a real-time routing system.

This publication may only be purchased from the NTIS. (PB No. 208441/AS, Price code: A03.)

Proceedings: Fourth International Conference on Concrete Pavement Design and Rehabilitation, Publication No. FHWA-RD-89-208

by Pavements Division

This publication lists the technical sessions and contains preprints of 56 papers accepted for publication or presentation at the conference held on April 18-20, 1989 in West Lafayette, Indiana. Virtually all phases of highway and airport pavement evaluation, design, construction, and rehabilitation are discussed.



Technical sessions were conducted on design theories and pavement performance; rehabilitation, pavement evaluation and overlays; and pavement design and economic analysis. Sessions also discussed design and rehabilitation of airfields; evaluation and testing; recycling and construction; and joints, bases, and drainage. Nineteen of the technical papers are from various foreign countries or organizations which made this a truly international conference.

This publication may only be purchased from the NTIS. (PB No. 89-217293/AS, Price code: A99.) It is also available from Purdue University, West Lafayette, IN.

New Research in Progress

The following new research studies reported by the FHWA's Office 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:

- **FHWA Staff and Administrative Contract Research contact** *Public Roads.*
- **Highway Planning and Research (HP&R) contact the performing State highway or transportation department.**
- **National Cooperative Highway Research Program (NCHRP) contact the Program Director, NCHRP, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC 20418.**
- **Strategic Highway Research Program (SHRP) contact the SHRP, 818 Connecticut Avenue, NW, 4th floor, Washington, DC 20006.**

NCP Category A—Highway Safety

NCP Program A.2: Improved Driver Visibility of Roadway Environment

Title: Sign Face Materials (NCP No. 4A2A0252)

Objective: Compare the cost effectiveness of sign materials considering initial cost, maintenance, and maintained reflectance. Investigate the relationship between laboratory accelerated testing, field test deck data, and inservice sign performance, for use in testing new materials.

Performing Organization: New Jersey Department of Transportation, Trenton, NJ 08623

Expected Completion Date: August 1995

Estimated Cost: $309,462 (HP&R)

Title: Snowplowable Raised Pavement Markers Wear and Improvement (NCP No. 4A2B0172)

Objective: Identify the factors relating to reflector wear on snowplowable raised pavement markers (SRPM). Investigate ways to improve the durability without modifying the reflectors or castings—including adhesive substitutes for installing castings. Determine the average reflector wear in the State per year and the typical variation. Review the use of hot melt and other adhesives to see if breakage can be reduced and durability of reflector increased.

Performing Organization: New Jersey Department of Transportation, Trenton, NJ 08623

Expected Completion Date: December 1992

Estimated Cost: $123,485 (HP&R)

Title: Safer Driving During Night Conditions (NCP No. 4A2A2092)

Objective: Define the primary factors which contribute to the disparity between day and night accident rates. Develop strategies to reduce the night accident rate (three times higher than during the day). Consider driver safety needs: visibility of traffic control devices and roadside hazards; changes in driver behavior; modifications of traffic control and road way elements; and development of forgiving roadside design.

Performing Organization: The Last Resource Inc. Bellefonte, PA 16823

Funding Agency: Pennsylvania Department of Transportation

Expected Completion Date: November 1990

Estimated Cost: $124,979(HP&R)

NCP Program A.5: Design

Title: Compendium of Safety Effectiveness of Highway Design Features (NCP No. 3A5A0292)

Objective: Review past safety studies (no more that 10 years old). Determine the most probable relationships between highway design features and safety. Evaluate the validity of the findings of each past study based on such factors as the experimental design used, the statistical techniques used, the sample size, and the interpretation of the findings. Develop a simple procedure for applying these safety relationships in evaluating alternative highway design improvements. Identify areas where safety relationships have not been quantified, and develop research work plans to fill the identified "gaps."

Performing Organization: The Scientex Corporation, Washington, DC 20006

Expected Completion Date: July 1992

Estimated Cost: $250,191(FHWA Administrative Contract)

Title: Analysis of In-Depth Guardrail and Median Barrier Accidents (NCP No. 3A5B1182)

Objective: Review some 1,150 accident cases investigated under a previous effort. Reconstruct accidents to estimate speed of impact and other key variables. Analyze the data to provide insight into the performance of our current inventory of roadside hardware. Analyses will include comparisons of various rail designs, effects of vehicle size on performance, importance of secondary collisions, etc.

Performing Organization: The Scientex Corporation, Washington, DC 20006

Expected Completion Date: February 1992

Estimated Cost: $225,021(FHWA Administrative Contract)

NCP Program A.9: Technology Transfer for Highway Safety

Title: Expert System for Bridge Rail Design (NCP No. 4A9E0333)

Objective: Develop a microcomputer-based expert system for the analysis and design of bridge rails. The system will incorporate judgment, intuition, experience, and other expertise of recognized bridge engineers to aid less knowledgeable engineers in solving bridge rail problems. The system is being designed with the expert system shell NEXPERT and will utilize FORTRAN subroutines for numeric analyses such as cost-benefit algorithms and dynamic crash simulations.

Performing Organization: Texas Transportation Institute, College Station, TX 77843

Funding Agency: Texas State Department of Highways and Public Transportation

Expected Completion Date: August 1991

Estimated Cost: $157,600(HP&R)

NCP Category B—Traffic Operations

NCP Program B.1: Traffic Management Systems

Title: Traffic Management Planning for Evacuations and Major Emergencies (NCP No. 4B1A2092)

Objective: Determine current practices and technology for traffic management and public information techniques for evacuations and major emergencies. Define Texas State Department of Highways and Public Transportation's traffic management role for major emergencies and evacuations. Develop a framework for preparing and implementing major emergency traffic management procedures. Develop guidelines and training aids to assist in implementing emergency action plans and traffic management procedures.

Performing Organization: Texas Transportation Institute, College Station, TX 77843

Funding Agency: Texas State Department of Highways and Public Transportation

Expected Completion Date: August 1991

Estimated Cost: $110,000(HP&R)

NCP Program B.9: Technology Transfer for Traffic Operations

Title: Urban Highway Operations Research and Implementation Program (NCP No. 4B9B0065)

Objective: Develop an urban highway operations research program. Develop a *Texas Highway Operations Manual.* Define issues for highway operational improvements, and specific research studies identified by the study's advisory committee.

Performing Organization: Texas Transportation Institute, College Station, TX 77843

Funding Agency: Texas Department of Highways and Public Transportation

Expected Completion Date: August 1994

Estimated Cost: $2,500,000 (HP&R)

NCP Category C—Pavements

NCP Program C.2: Evaluation of Flexible Pavements

Title: Subgrade Resilient Modulus for Pavement Design and Evaluation (NCP No. 4C2B1252)

Objective: Develop the capability to perform resilient modulus testing on soils. Develop a resilient modulus data base for Indiana soils. Determine the role that the subgrade has in pavement design and performance. Develop limiting criteria for subgrade deformations. The triaxial testing method of AASHTO T274 will be used with variations in compaction, water content, and freezing cycles.

Performing Organization: Purdue University, Indiana Joint Highway Research Project, West Lafayette, IN 47906

Funding Agency: Indiana Department of Highways

Expected Completion Date: March 1993

Estimated Cost: $221,566(HP&R)

NCP Program C.3: Field and Laboratory Test Methods

Title: Automated Equipment for Characterizing the Properties and Thickness of Pavement Layers (NCP No. 4C3A2632)

Objective: Develop an automated, simple to use procedure for reducing the field data collected by the Spectral Analysis of Surface Waves method. Develop a rapid method for determining the modulus and thickness of surface layers. Develop a prototype device to rapidly delineate discontinuities in pavements.

Performing Organization: Center for Transportation Research, University of Texas, Austin, TX 78712

Funding Agency: Texas Department of Highways and Public Transportation

Expected Completion Date: August 1992

Estimated Cost: $345,000 (HP&R)

NCP Program C.4: Management Strategies

Title: Expediting Urban Pavement Construction (NCP No. 4C4C2122)

Objective: Define and categorize sites which would benefit from expediting pavement construction. Examine design, equipment, and materials consequences. Define user benefits and local economic impacts to allow full spectrum of costs to be evaluated.

Performing Organization: Center for Transportation Research, University of Texas, Austin, TX 78705

Funding Agency: Texas State Department of Highways and Public Transportation

Expected Completion Date: August 1992

Estimated Cost: $477,100(HP&R)

NCP Category D—Structures

NCP Program D.1: Design

Title: Bracing Effects of Bridge Decks (NCP No. 4D1A3392)

Objective: Demonstrate, theoretically and experimentally, the lateral bracing effects of decks—many off-system bridges in Texas are constructed with steel stringers supporting a timber plank deck, nail laminated timber deck, or concrete deck with no positive connection between these stringers and the deck. Test beams with bracing systems for stability and a bridge with a wooded deck to failure.

Performing Organization: Center for Transportation Research, University of Texas, Austin, TX 78712

Funding Agency: Texas State Department of Highways and Public Transportation

Expected Completion Date: August 1991

Estimated Cost: $230,300 (HP&R)

Title: Instrumentation of Segmental Box Girder Bridges and Multi-piece Winged Boxes (NCP No. 4D1A3492)

Objective: Identify major design uncertainties and areas where field verification of assumptions are necessary in segmental box girders. Instrument selected segments and spans to obtain construction and environmental behavior information. Propose changes to the "AASHTO Interim Design and Construction Provisions for Segmental Box Girder Construction."

Performing Organization: Center for Transportation Research, University of Texas, Austin, TX 78712

Funding Agency: Texas State Department of Highways and Public Transportation

Expected Completion Date: August 1992

Estimated Cost: $340,000 (HP&R)

Title: Thermal Response of Florida Bridges (NCP No. 4D1A3402)

Objective: Make field measurements of temperature distribution and thermal movements of typical concrete bridges in Florida. Compare the field data with predicted temperatures from analytic model. Study the effect of thermal stresses on bridge serviceability and integrity. Validate the current guidelines for designing for thermal forces. This study seeks to calibrate the proposals from the National Cooperative Highway Research Program (NCHRP) Project 12-22 that were incorporated into the American Association of State Highway and Transportation Officials (AASHTO) specifications.

☆ U.S. Government Printing Office: 1989—261-345/20000

Performing Organization: Florida Atlantic University, Boca Raton, FL 33431

Funding Agency: Florida Department of Transportation

Expected Completion Date: August 1991

Estimated Cost: $271,000(HP&R)

Title: Effect of Increased Truck Weight on Illinois Highway Bridges (NCP No. 4D1B4012)

Objective: Develop an analytical procedure for determining the remaining service life of bridges subjected to increased load. Investigate the potential growth in the use of heavier trucks on highway bridges. Conduct a bridge user cost analysis to determine the potential increased repair/maintenance cost.

Performing Organization: Illinois Transportation Research Consortium, Evanston, IL 60201

Funding Agency: Illinois Department of Transportation

Expected Completion Date: December 1990

Estimated Cost: $111,507 (HP&R)

NCP Program D.4: Corrosion Protection

Title: Mechanism of Corrosion of Epoxy-Coated Reinforcing Steel in Concrete (NCP No. 4D4C0582)

Objective: Formulate a corrosion mechanism for epoxy-coated reinforcing steel in chloride contaminated concrete by integrating and supplementing the information disclosed by the previous research. Based on the formulated mechanism of corrosion, evaluate repair methods for the rehabilitation of existing reinforced structures containing epoxy-coated rebars in marine environments.

Performing Organization: University of South Florida, Tampa, FL 33620

Funding Agency: Florida Department of Transportation

Expected Completion Date: August 1990

Estimated Cost: $74,990 (HP&R)

NCP Category E—Materials and Operations

NCP Program E.1: Asphalt and Asphalt Mixtures

Title: Establishment of Acceptance Limits for the 4-Cycle Magnesium Sulfate Soundness (MSS) and Modified Wet Ball Tests for Aggregates used in Seal Coats and Surface Courses (NCP No. 4E1D2012)

Objective: Collect 4-cycle MSS and modified wet ball test results. Develop a procedure for establishing test limits. Identify projects which used the aggregates tested. Collect field performance data related to properties of the aggregates under test. Analyze the laboratory and field data and set acceptance limits. Write proposed specifications.

Performing Organization: Center for Transportation Research, University of Texas, Austin, TX 78712

Funding Agency: Texas State Department of Highways and Public Transportation

Expected Completion Date: August 1991

Estimated Cost: $200,200 (HP&R)

NCP Program E.2: Cement and Concrete

Title: Training Course on Concrete Proportioning (NCP No. 4E2A2033)

Objective: Develop a 2-day training course on concrete proportioning for the Illinois Department of Transportation. Analyze user needs; plan course; produce course details and deliverables; and evaluate the results.

Performing Organization: Southern Illinois University, Carbondale, IL 62901

Funding Agency: Illinois Department of Transportation

Expected Completion Date: September 1990

Estimated Cost: $74,747 (HP&R)

U.S. Department
of Transportation

**Federal Highway
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