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United States General Accounting Office

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Report to the Chairman, Subcommittee on Investigations and Oversight, Committee on Public Works and Transportation, House of Representatives

November 1987

HIGHWAY TECHNOLOGY

The Structure for Conducting Highway Pavement Research

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Program Evaluation and
Methodology Division

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November 13, 1987

The Honorable James L. Oberstar
Chairman, Subcommittee on Investigations and Oversight
Committee on Public Works and Transportation
House of Representatives

Dear Mr. Chairman:

This report is in response to your June 2, 1987, letter requesting background information about the U.S. highway system and how research efforts to develop highway technologies are currently structured. This request reflects the subcommittee's interest in cost-effective ways of maintaining and rehabilitating our highways. Our staff is currently analyzing information in response to your earlier request that we determine how states decide to adopt or reject highway pavement technologies. As you requested, the present report describes the environment of the research on highway pavement technologies. We present background information on the highway system and its financing, the current structure for conducting highway research, and how research and new technologies are expected to help improve the highways.

As you know, the Congress has refocused the federal-aid program toward maintaining and improving the existing highway system. The Surface Transportation and Uniform Relocation Assistance Act of 1987 authorized $2.8 billion per year for fiscal years 1987-91 for resurfacing, restoring, rehabilitating, and reconstructing existing interstate facilities, a slight increase over previous legislation. For interstate construction, this act reduced the authorization from the $4 billion per year authorized in previous legislation to approximately $3 billion per year for fiscal year 1987 and $3.15 billion for fiscal years 1988-92. In terms of funding, the interstate construction program is still the larger of the two federal-aid programs.

State expenditures on highways for all purposes amounted to about $41 billion in 1985. About 30 percent of this came from federal funds. Current estimates indicate that this level of expenditure may not be adequate. The Federal Highway Administration (FHWA) projects that by the year 2000, approximately 41,000 miles of interstate highways, 334,000 miles of arterial roads, and 636,000 miles of "collectors" will require capital improvements to maintain their serviceability.

Research and decisions about the use of highway pavement technologies will play an important role in determining how current and future highway needs are met. For highway pavement technologies, state highway agencies need not only new materials that improve highway service and reduce costs but also new procedures and techniques. Research on how to improve highway rehabilitation materials and techniques can assist in developing cost-effective methods of preserving the U.S. highway system. No one technology will solve pavement problems, but better materials would help.

To develop the information you requested, we interviewed experts in highway technologies, FHWA officials, and highway officials in Arizona, California, Colorado, and Pennsylvania, and we surveyed the relevant body of highway research. FHWA provided oral comments and agreed with the basic description of the issues discussed, suggesting only minor changes to improve technical accuracy. We made changes based on these comments where appropriate.

In our next report, we intend to provide the results of our analysis of how states decide to use highway pavement technologies. We expect to address the problems the states encounter, including barriers preventing innovation and incentives that may encourage the adoption of technologies.

As we arranged with your office, copies of this report will be sent to the Federal Highway Administration. We will also make copies available to interested organizations, as appropriate, and to others upon request. If you have any questions or would like additional information, please call me or Mr. Richard Barnes at (202) 275-3593.

Sincerely yours,

Carl E. Wisler

Carl E. Wisler
Associate Director

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Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ATAC	American Transportation Advisory Council
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
NCP	Nationally Coordinated Program
NHI	National Highway Institute
SHRP	Strategic Highway Research Program
TRB	Transportation Research Board

Scope and Methodology

The Chairman of the Subcommittee on Oversight and Investigations of the House Public Works and Transportation Committee has expressed concern as to whether cost-effective approaches are being considered in constructing, reconstructing, and maintaining U.S. highways. In response to this interest, we are studying how the states choose highway pavement technologies. As requested, this initial report provides background information on the highway system and the structure of research efforts to develop highway technologies. This report also contains information on how research could be expected to assist in providing highway pavement technologies that improve the highways or reduce their costs.

For our analysis, we defined "technology" as any product, material, or method intended to improve highway construction or rehabilitation. Improving highway construction and rehabilitation involves extending pavement life by reducing its deterioration or its construction or maintenance costs.

We interviewed Federal Highway Administration officials and experts in research on highway pavement technologies, and we conducted field visits in four states (Arizona, California, Colorado, and Pennsylvania) in order to study highway research efforts. Our analysis of this information is presented here in response to the subcommittee's request.

We believe that research on and the development of highway pavement technologies can improve U.S. highways by pointing to opportunities for cost savings and more efficient performance. However, it appears from our preliminary work that research efforts are currently fragmented and uncoordinated and that the states face a variety of barriers in implementing the many existing highway pavement technologies.

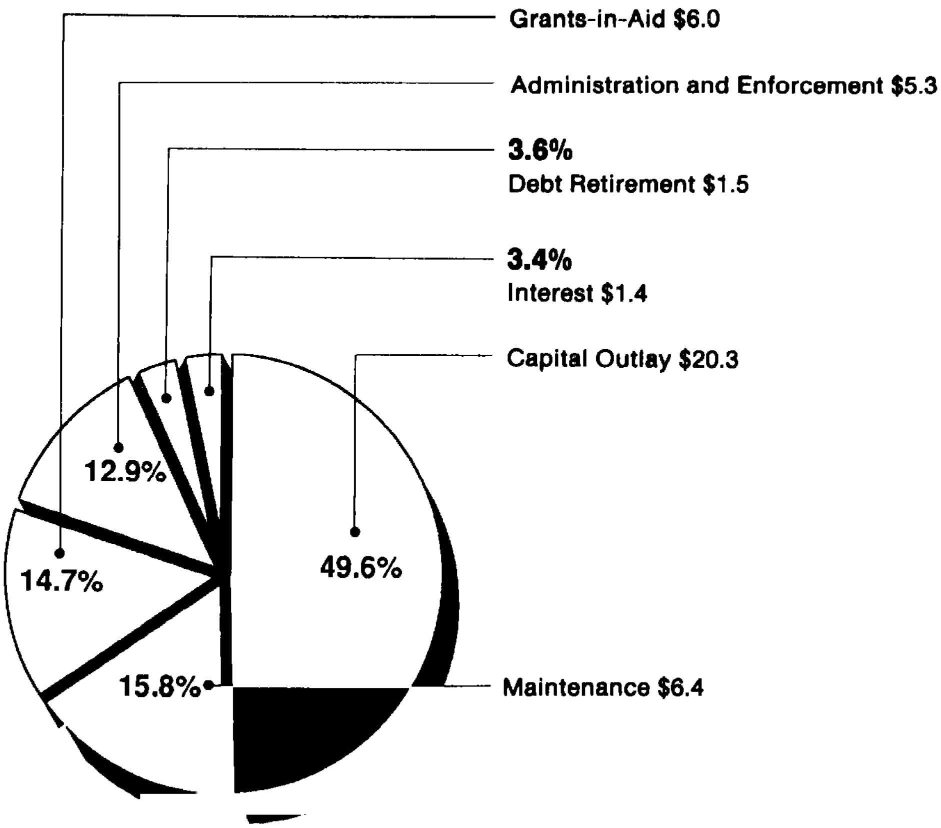
This report should serve as a contextual document for our next report, in which we intend to respond to the following policy question: What are the principal factors that determine the adoption of or lead to the rejection of competing highway pavement technologies, and to what extent are decisions based on criteria of cost or performance or both?[1]

[1]Pavement "performance" includes structure as well as function. Structural performance relates to the pavement's physical condition—cracking, faulting, or other conditions that adversely affect the load-carrying capability of the structure or that require maintenance. Functional performance relates to how well the pavement serves the user.

The U.S. Highway System

The components of the U.S. highway system vary widely with respect to their capacity and condition and the demands placed on them. The highway system is the most visible and extensively used modern public works facility, and it contributes significantly to the nation's productive capacity. State expenditures on highways for all purposes amounted to about $41 billion in 1985 (see figure 2.1). Estimates of the replacement value of the existing capital stock range from $1 trillion to $3 trillion. The U.S. investment in the highway infrastructure is clearly significant.

Figure 2.1: 1985 State Disbursements for Highways[a]



[a]Dollars are in billions. The total is $40.9 billion.

Source: Federal Highway Administration, Highway Statistics 1985 (Washington, D.C.: U.S. Government Printing Office, 1986), p. 7.

Federal aid for highways is governed by the laws embodied in title 23 of the United States Code, which have changed considerably over the years, although they retain many of their original characteristics. Historically, federal aid has concentrated on new construction, and the states have been responsible for road repair. However, the Surface Transportation and Uniform Relocation Assistance Act of 1987 reduced the authorization for interstate construction from the $4 billion per year authorized in 1982 legislation to approximately $3 billion per year for fiscal year 1987 and $3.15 billion for fiscal years 1988 through 1992. Moreover, beginning in 1976, the Congress authorized interstate funds specifically for use in resurfacing, restoration, and rehabilitation. The Federal-Aid Highway Act of 1981 added reconstruction to these activities, and the Surface Transportation Assistance Act of 1982 increased the funds provided for all four activities. Their authorization for fiscal years 1987-91 is $2.8 billion per year.

The national network for trucks established by the Surface Transportation Assistance Act of 1982 allowed larger and heavier trucks to use the highways. Combinations of truck-tractors with 48-foot trailers and truck-tractors with 28-foot twin trailers are allowed up to 102 inches wide with no overall length limitations. While the Surface Transportation and Uniform Relocation Assistance Act of 1987 temporarily modified the length permitted between tandem axles in some instances, the 1982 provisions generally remain unchanged.

According to the Transportation Research Board (TRB), a unit of the National Research Council of the National Academy of Sciences, benefits accrue to the economy from large, heavily loaded vehicles, but heavily loaded traffic has a destructive effect on highway pavements.

In the rest of this section, we present information about the characteristics of roads, the composition of federal-aid highway financing, and changes in the federal and state roles relative to the highway system.

The Characteristics of Roads

Asphalt dominates the nation's highway industry. Ninety-four percent of all surfaced roads in the United States are paved with asphalt—some 2 million miles. About one fourth of the nation's overall expenditure on highways is for asphalt pavements. This share—about $10 billion per year—is growing as the nation's highway program increasingly turns to rehabilitation, in which asphalt has a dominant role. Asphalt is a flexible pavement that maintains contact with and distributes loads to the subbase or subgrade. Roads made of asphalt depend on aggregate interlock, particle friction, and cohesion for stability.[1]

The chemical composition of asphalt is so complex that attempts to identify its chemical characteristics have been unsuccessful. One researcher thinks there may be a range of asphalts that could be used in different climates or geographical areas. According to the director of the Texas Transportation Institute, however, the highway industry currently lacks basic knowledge about the characteristics of asphalt mixes and how to relate them to performance.

One major classification of roads identifies them by visible surface type. Many highways, whether by original design or because of reconstruction, consist of more than one major type of construction material. In addition, as table 2.1 shows, in 1985 more than 122,000 miles of U.S. roads were paved with concrete. The United States had approximately 3.9 million miles of roads in 1985, almost half of which were unpaved. Of the total, 3.2 million miles were rural roads and 0.7 million miles were urban. Roads are eligible for federal funds because of their service value and importance, regardless of whether they are state or county roads or city streets.

Table 2.1: 1985 U.S. Road and Street Mileage by Surface Type

Surface	Rural	Urban	Total
Paved			
Asphalt[a]	1,407,887	578,543	1,986,429
Concrete	54,805	67,657	122,462
Unpaved	1,708,295	44,747	1,753,042
Total	**3,170,987**	**690,947**	**3,861,934**

[a]Asphalt includes all types of roads that have a bituminous surface layer This includes earth, gravel, and stone roads that have a bituminous surface layer less than 1 inch thick (low-type flexible pavement), roads with a bituminous surface layer less than 7 inches thick (intermediate-type flexible pavement), and roads with a bituminous surface layer greater than 7 inches thick (high-type flexible pavement)

Road concrete, or Portland cement concrete, is also the most commonly used material for bridge decks, median dividers, curbs, and sidewalks. Concrete pavement may be either continuously reinforced or jointed, and it is rigid because it has as one layer a slab of concrete with a relatively high resistance to bending. Its rigidity distributes loads to the subgrade.

[1]Important elements in holding asphalt pavement together and limiting distortion and pavement rutting. Engineers try to provide cohesion by using well-graded aggregate of rough textures. (See the glossary at the end of this report.)

The presence of water under the concrete slabs is a major factor in the deterioration of concrete pavement. According to an official of the Portland Cement Association, drainage in wet regions is an essential requirement for satisfactory pavement. To ensure that moisture will not reduce the life of a pavement, all major sources of water infiltration must be sealed. In cold climates, damage often results when the water freezes and cracks the pavement.

The federal government owns and maintains only about 226,000 miles of roads, or about 6 percent of the total road mileage, mainly roads in national parks, forests, and other government-owned lands. Local units of government have jurisdiction over the bulk of the mileage—2.8 million miles, or 72 percent. The states own 22 percent of the total road mileage, for a total of about 860,000 miles. (See table 2.2.)

Table 2.2: 1985 Jurisdictional Control of U.S. Roads by Miles

Jurisdiction	Supported with federal aid	Not supported with federal aid	Total
Federal	1,223	224,980	226,203
State	528,703	332,674	861,377
Local	313,383	2,460,971	2,774,354
Total	**843,309**	**3,018,625**	**3,861,934**

The Federal-Aid Highway System

The core of the federal highway program is the federal-aid highway system. Although the federal-aid system consists of only 22 percent of the total mileage, or about 843,000 miles, it handles approximately 80 percent of all travel in the nation. The system consists of four categories of designated routes: interstate, primary, secondary, and urban (see table 2.3). Designating a highway as part of the federal-aid system does not mean that it is owned, operated, or maintained by the federal government. It simply indicates the eligibility of state and local road systems for federal assistance.

Table 2.3: The 1985 Federal-Aid Highway System in Miles of Roads and Vehicle Travel

	Roads		Vehicle travel	
Category	**Miles**	**Percent**	**Miles**	**Percent**
Federal aid	843,309	21.8	1,427,915	80.5
Interstate	43,593	1.1	370,589	20.9
Primary	257,413	6.7	518,632	29.2
Secondary	398,248	10.3	155,959	8.8
Urban	144,055	3.7	382,735	21.6
Nonfederal aid	3,018,625	78.2	346,847	19.5
Total	**3,861,934**	**100.0**	**1,774,762**	**100.0**

Another way FHWA groups roads is into functional classes according to the type of service they provide:

- Arterials are highways that move large numbers of vehicles quickly from one place to another. Characterized by long-distance travel, high volumes, and higher speeds than other facilities, they account for 10 percent of all road mileage but 69 percent of the total vehicle miles of travel.
- Local roads and streets provide access to farms and other rural resources or to urban businesses and residences. People usually travel short distances at low speeds on local roads and streets, which constitute 69 percent of all road mileage but only 13 percent of the total vehicle miles of travel.
- Collectors are routes that gather vehicles from local roads and funnel them into arterials. They make up 21 percent of all road mileage but carry only 18 percent of all vehicle miles of travel.

The interstate system, authorized by the Congress in 1944, is in the arterial class. It connects, as directly as possible, the nation's principal metropolitan areas and industrial centers. It serves the national defense and connects with routes of continental importance at suitable border points. The interstate system consists of 43,593 miles and receives the most federal funding. Interstate highways account for only 1 percent of the nation's total miles of roadway, but they carry about 21 percent of the total vehicle miles of travel.

Federal assistance for the primary highway system dates back to 1916. Today, the primary system consists of 257,413 interconnected miles of rural routes and urban extensions of them that are classified as arterials. The primary highways are usually U.S.-numbered roads—U.S. 1, for example—and are similar in character to interstate routes. They carry about 29 percent of the vehicle miles of travel.

The secondary system, established in 1944, comprises rural routes that are classified as major collectors, such as farm-to-market roads and county and local roads, including the more important of the intracounty routes. The roads in this system, unlike those in the primary system, do not form an interconnected network of highways. Instead, they separately funnel traffic onto and off a state's arterial network. The secondary system totals about 398,248 miles but only about 9 percent of the vehicle miles of travel.

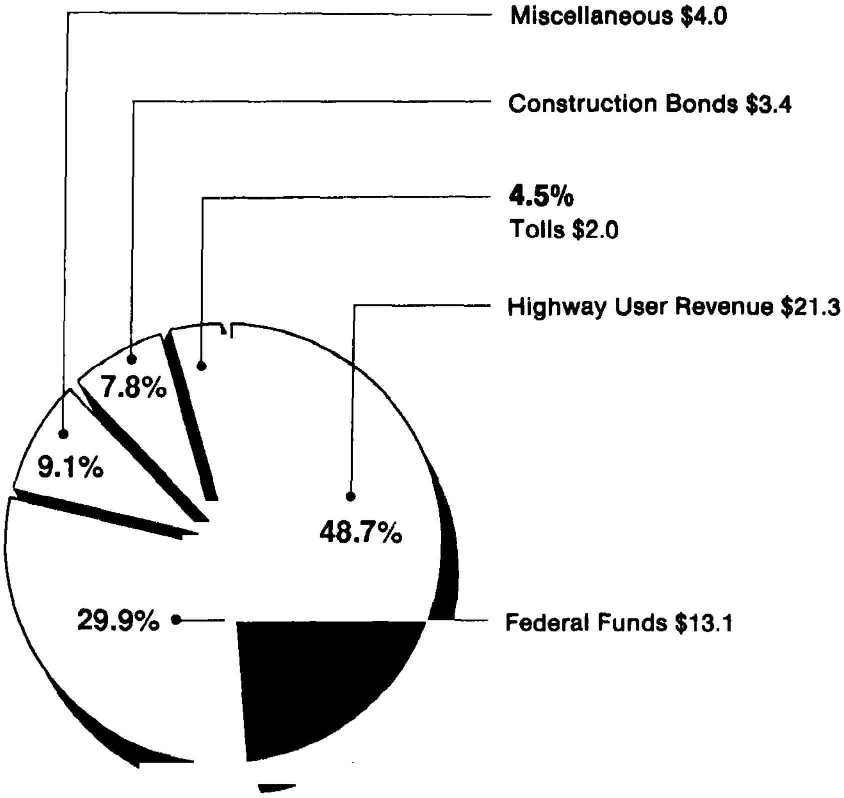
In 1970, the Congress instituted a fourth network of federal-aid roads called the "urban system." It consists of about 144,000 miles of arterials and collectors in urban areas (places with 5,000 or more population). This system serves major centers of activity and includes high-volume arterial and collector routes that carry more than 21 percent of all vehicle miles of travel.

Highway Financing

The federal-aid highway program is a federally assisted, state-administered program funded primarily through taxes on highway use. These "highway-user" taxes are federal, state, and local taxes levied on users of highway facilities, those who use the facilities the most paying the largest tax. Included are fuel taxes, drivers' license and automobile registration fees, and special taxes on heavy vehicles and vehicle parts and accessories. For example, when the Surface Transportation Assistance Act of 1982 raised the federal gasoline tax by 5 cents per gallon to 9 cents, it earmarked 1 cent for public transit capital costs, broadened the funding base for each state's federal-aid highway apportionment, and increased the amount of funds available for transportation improvements.

Total federal and state revenues from user taxes were approximately $33 billion in 1985. The states collected about $21 billion of this while the federal government collected about $12 billion. Federal user taxes accounted for about 23 percent of state highway receipts while all federal funds accounted for about 30 percent, or about $13 billion. State user taxes accounted for about 49 percent of all state receipts for highways in 1985. (See figure 2.2.) User taxes accounted for 69 percent of all state-generated receipts and 78 percent of all federally generated receipts in 1985.

Figure 2.2: 1985 State Receipts for Highways[a]



[a]Dollars are in billions. The total is $43.8 billion.

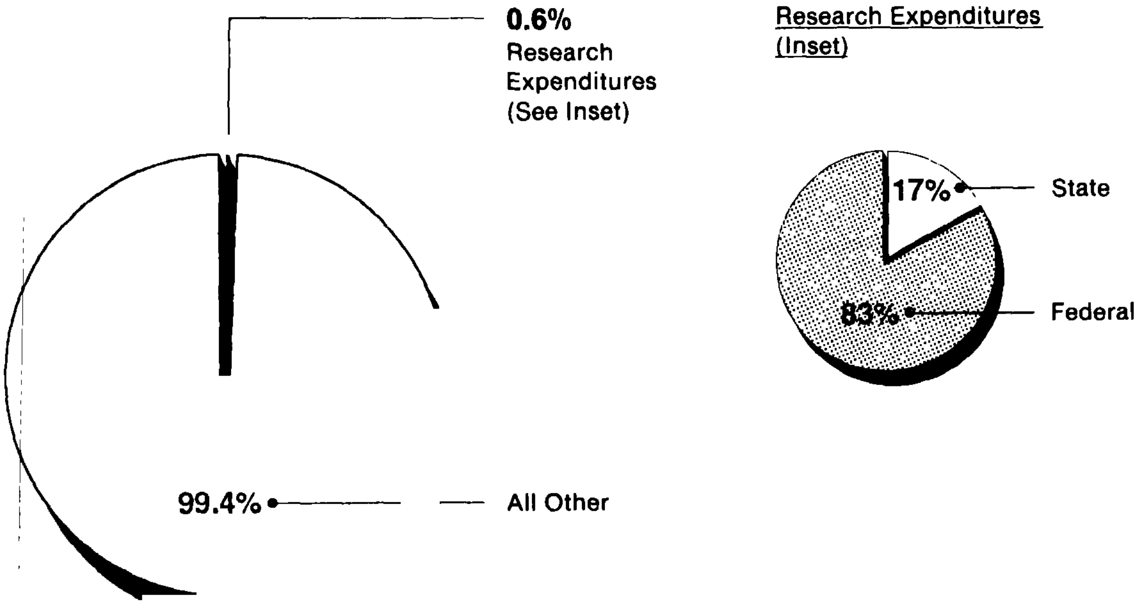
Source: Federal Highway Administration, Highway Statistics 1985 (Washington, D.C.: U.S. Government Printing Office, 1986), p. 99.

The federal-aid highway program is financed through the highway trust fund, established by the Highway Revenue Act of 1956. Revenues from taxes accrue to the fund and are dedicated to use on federal-aid roads. Because the Congress did not enact the highway trust fund permanently, it must be extended periodically to continue. Under present law, all highway-user taxes dedicated to the fund are scheduled to terminate on September 30, 1993.

In fiscal year 1985, highway trust fund revenues amounted to $14.326 billion; among the uses for these revenues, $12.906 billion was earmarked for highways. Only about 0.6 percent of the fund's revenues were spent on research. This amount, some $83 million, provided about

83 percent of all money devoted to highway research in that year. At the conclusion of fiscal year 1985, the balance of the trust fund was $12.885 billion, of which $10.361 billion was reserved for highway purposes. (See figure 2.3.)

Figure 2.3: The Percentage of 1985 Highway Trust Fund Expenditures Devoted to Research



Under the federal-aid highway program, the federal government reimburses the states for costs they incur. After the Congress authorizes funds for the various program categories, FHWA then apportions most of them to the states according to formulas prescribed by law. Table 2.4 shows that the interstate and primary systems and bridges currently receive the most federal funding support. Interstate substitution projects and the secondary and urban systems receive fewer federal funds—less than $1 billion each per year.[2]

[2]The interstate substitution projects are primarily nonhighway public transportation projects funded by money that would otherwise be spent on the interstate highway system, although amendments to the Federal Highway Act of 1987 now allow the money to be used for highways and street improvement projects as well as for public transportation projects.

Table 2.4: Federal-Aid Highway Authorizations for Fiscal Years 1987-91[a]

Category	1987	1988	1989	1990	1991
Major systems					
Interstate					
Construction	$3,000	$3,150	$3,150	$3,150	$3,150
Resurfacing, restoration, rehabilitation, and reconstruction	2,815	2,815	2,815	2,815	2,815
Substitution projects	740	740	740	740	740
Primary	2,325	2,325	2,325	2,325	2,325
Secondary	600	600	600	600	600
Urban	750	750	750	750	750
Bridges	1,630	1,630	1,630	1,630	1,630
Total	**$11,860**	**$12,010**	**$12,010**	**$12,010**	**$12,010**
Other	$1,715	$1,727	$1,727	$1,876	$1,876
Total	**$13,575**	**$13,737**	**$13,737**	**$13,886**	**$13,886**

[a]These figures are in millions of dollars authorized under title I of the Surface Transportation and Uniform Relocation Assistance Act of 1987.

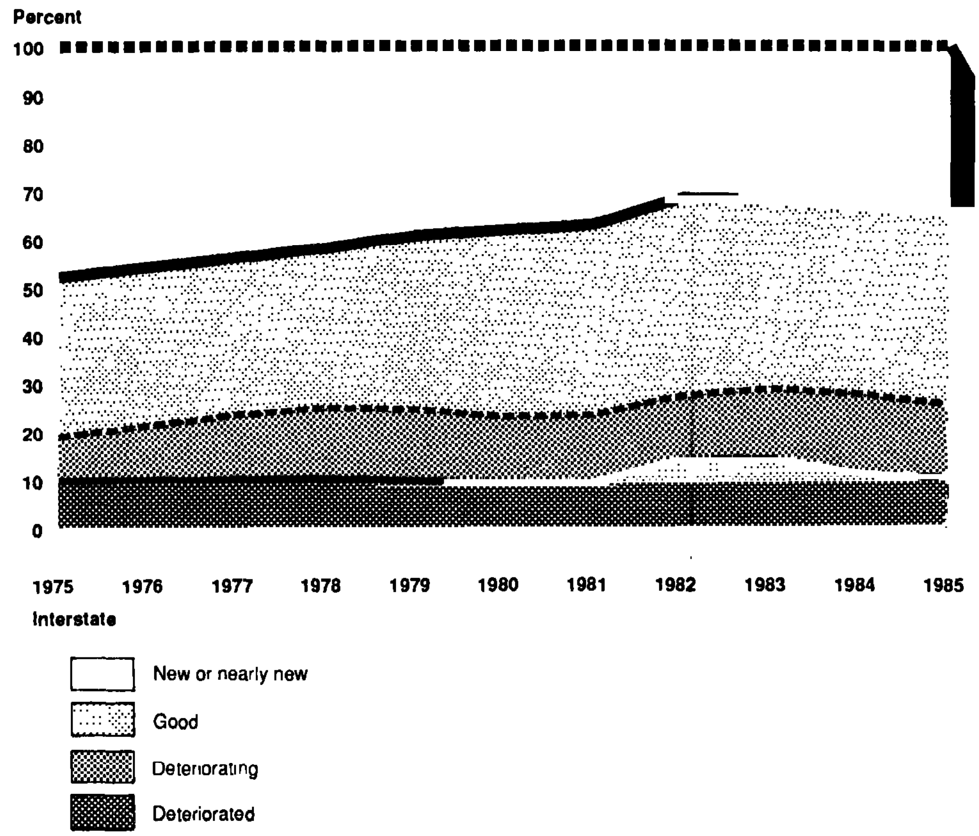
Although FHWA allocates some funds to the states at its own discretion, it allocates most funds according to legislatively mandated formulas. Once the funds are apportioned or allocated, the states are at liberty to obligate their funds. An annual appropriation act of the Congress then provides the cash to liquidate their obligations. The money is transferred to the states after they submit vouchers for completed work.

This ability, called "contract authority," permits the agency to incur obligations for the full amount authorized in advance of appropriation actions by the Congress. To have contract authority, a highway program must meet two criteria:

- it must be encompassed in chapter 1 of title 23 of the United States Code, or its authorizing language must refer to chapter 1, and
- the program must be financed from the highway trust fund.

The highway trust fund's revenues may not be adequate for meeting projected federal-aid highway needs. The portion of total mileage in the interstate system in new or nearly new condition decreased from 47.7 percent in 1975 to 34.3 percent in 1985. The portion of total interstate mileage in deteriorating and deteriorated condition increased from 19.1

Figure 2.4: The Relative Condition of Interstate and Other Arterial Highway Pavement in 1975-83[a]



[a] For any given year, the percent for each condition is computed by taking the difference between the upper and lower curves, along the vertical axis. For example, in 1975, the percent of new or nearly new interstate highways was 100 percent minus 52.33 percent, or 47.67 percent.

Source: Adapted from Federal Highway Administration, Our Nation's Highways: Selected Facts and Figures (Washington, D.C.: 1985), p.6. Additional data from Federal Highway Administration, memorandum, Washington, D.C., August 16, 1987.

percent in 1975 to 25.7 percent in 1985. (Pavement condition is determined from a "present serviceability rating," or "psr," in FHWA's highway performance monitoring system. The psr is a standard measure representing various stages of deterioration. See figure 2.4 and table 2.5.)

FHWA estimates that $12 to $14 billion will be generated each year under existing provisions for the trust fund, but a statement of investment

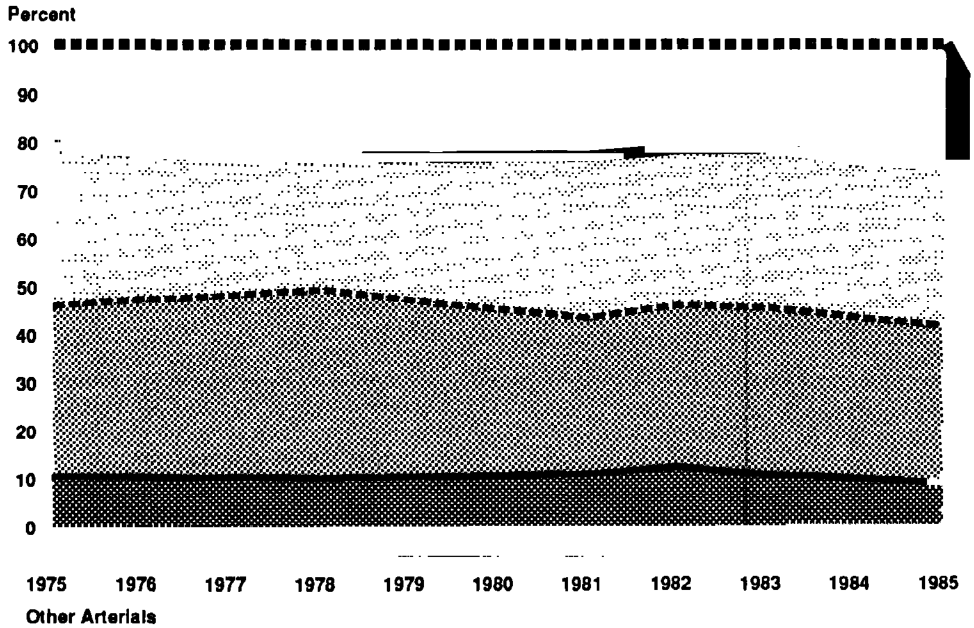


Table 2.5: The Condition of Interstate and Other Arterial Highway Pavement in 1985

Condition	Interstate Miles	Interstate Percent	Other arterials Miles	Other arterials Percent
New or nearly new	14,961	34 32	86,391	24 23
Good	17,424	39.97	121,510	34 08
Deteriorating	6,657	15.27	117,196	32.87
Deteriorated	4,551	10.44	31,447	8.82
Total	**43,593**	**100.00**	**356,544**	**100.00**

Source Federal Highway Administration, memorandum, Washington, D.C., August 16, 1987.

Table 2.6: Estimated Total Highway Investments Required for 1987-95[a]

Category	1987	1988	1989	1990	1991	1992	1993	1994	1995
Interstate									
Construction	$4.3	$4.5	$4.5	$4.6	$0.6	•	•	•	•
Resurfacing, restoration, rehabilitation, and reconstruction	3.4	3 5	3.6	3.8	3.9	$4 1	$4.2	$4.4	$4.6
Primary	5.0	5.2	5.4	5.6	5.8	6.1	6.3	6.5	6 8
Secondary	4.5	4.7	4.9	5.1	5.3	5.5	5.7	6 0	6 2
Urban	3.2	3.4	3.5	3.6	3 8	3.9	4.1	4.3	4 4
Bridges	5.2	5.4	5.7	5.9	6.1	6.4	6.6	6.8	7.1
Safety construction	0.4	0.4	0.5	0.5	0.5	0 5	0.5	0.6	0.6
Total	**$26.0**	**$27.1**	**$28.1**	**$29.1**	**$26.0**	**$26.5**	**$27.4**	**$28.6**	**$29.7**

[a]Dollars are in billions, allow for inflation at 4 percent per year, and include federal, state, and local funds

Source: American Transportation Advisory Council, New Directions in Transportation (Washington, D C 1985), p 19.

requirements issued by the American Association of State Highway and Transportation Officials (AASHTO) shows an average of $27.6 billion per year. For the 9-year period 1987 through 1995, AASHTO puts the total required highway investment at $248.5 billion. (See table 2.6.) This indicates a possible shortfall of approximately $138.5 billion.

Whether the investment shortfall is really this large is a matter of some debate. The American Transportation Advisory Council (ATAC), a coalition of private-sector highway interests, believes the shortfall estimates are probably very conservative. At least one Department of Transportation official believes FHWA's studies are more authoritative than studies having one or more of the following deficiencies:

- They do no more than pass on secondhand information.
- They collect some local data and perform tabulations that are suggestive but incomplete.
- Their analyses are superficial and self-serving.
- They deal with infrastructure problems in general and include highways only as examples, without attempts at original analysis.
- They offer no new empirical information, even though they are otherwise conceptually sound.

In contrast, FHWA's studies are based on an extensive system of reporting and modeling data.

Federal and State Roles

Since the inception of the federal-aid highway program in 1916, it has been envisioned as a partnership emphasizing federal and state cooperation. The Congress defined the states' role to include selecting, planning, designing, and constructing highway improvements and required each state to organize a highway department. The Congress also established the federal role of reviewing and approving work for which federal funds are used.

There is some concern today about what the national transportation policy should be. In the past, the focus was on completing the interstate highway system. However, diverse highway interests are currently promoting more parochial goals, and, as a result, the states identify less than they did in the past with a nationally stated transportation policy. An example is in the debate over provisions of the 1987 Surface Transportation Assistance and Uniform Relocation Act on increasing the uniform maximum speed limit from 55 to 65 miles per hour.

According to recommendations by ATAC in 1985, the federal role in transportation should primarily address capital investment needs. Table 2.7 shows that ATAC estimates that capital investment needs for highways are $494 billion for 1987-96 and that highways account for almost 75 percent of all capital needs for transportation.

Table 2.7: Capital Investment Needs for U.S. Transportation for Fiscal Years 1987-96[a]

System	Investment
Airports	$27.0
Highways	494 0
Public transit	82.6
Railroads	56.6
Waterways	6.6
Total	**$666.8**

[a]Current dollars are in billions and allow for inflation at 4 percent per year.

Source: American Transportation Advisory Council, New Directions in Transportation (Washington, D C · 1985), p 5

The federal role relative to highways might eventually be reduced. In the current economic and budgetary climate, it may be difficult for the federal government to find sources of new revenues for highways. AASHTO recommends establishing a system of highways of national significance that would include only the current federal-aid interstate and primary systems and bridges. The secondary and urban systems would be under state and local control. Moreover, some officials from the states, FHWA, and the Congress anticipate an increase in the role and responsibilities the states will have in maintaining the highway infrastructure.

State and local governments have historically functioned as the principal road builders, and because they are close to the current problems and issues, they are in a logical position to make transportation decisions. Highway maintenance is a state and local government responsibility. The resources state and local governments provide for highways have been growing at a faster rate than the federal share. As can be seen in table 2.8, local expenditures increased almost 8 percent per year between 1965 and 1982, and state expenditures increased 6.3 percent. In contrast, federal expenditures increased on the average about 5.7 percent per year.

Table 2.8: Federal, State, and Local Highway Expenditures in 1965-82[a]

Year	Federal	State	Local	Total
1965	$4.1	$7.1	$2.3	$13.5
1970	5.2	11.0	3.4	19.6
1975	7.2	14.3	5.7	27.2
1980	12.0	19.0	9.0	40.0
1982	10.5	20.0	8.4	38.9
Increase				
Overall	155%	183%	271%	189%
Annual	5.7%	6.3%	7.9%	6.4%

[a]Dollars are in billions

Source: American Association of State Highway and Transportation Officials, A New Focus for America's Highways: Recommendations on the Federal-Aid Highway Program (Washington, D.C. 1985), p 19

Although user fees continue to be the main source of income for highways, state and local transportation agencies are coping with fiscal constraints by finding additional sources of funding. Four sources they use are general funds, "impact" fees, exaction, and "turn-backs."

General Funds

According to FHWA and state officials, the states are increasingly turning toward general funds. The use of general funds rather than user fees raises questions of equity. Traditionally the principal method of financing highway projects, user fees are designed to tax the persons who use and benefit from the highway system the most. General funds, however, are taxes obtained from the entire community without regard to highway use. But as more and more members of the population become licensed automobile drivers, the use of general funds for highways is less likely to subsidize one group (drivers) at the expense of another (nondrivers).

Impact Fees

"Impact" fees are charged to help pay for the effect that new housing and other developments have on roads. They are based on schedules reflecting the benefits that landowners, whether homeowners or businesses, receive from the expansion of or from having access to transportation facilities.

Exaction

Exaction is a process in which developers agree to pay a fee prior to constructing new developments that will require transportation improvements. A developer may pay all or some of the costs of new or improved roads that bear increased traffic from the development, depending on the outcome of negotiations with the state or local jurisdiction.

Turn-Backs

A state may give control of, or "turn back," roads to municipalities and other local governments. Some highway improvements may be accomplished quickly and economically when performed at the local level. Local governments might be able to execute local highway projects with less red tape and fewer limitations from states and the federal government.

The Structure for Conducting Highway Research

The state and local highway agencies and FHWA share responsibilities for developing and selecting the best possible highway pavement technologies. The states and FHWA cooperatively support a large portion of the research and development through the highway planning and research program, which in fiscal year 1985 constituted 45 percent of total U.S. highway research. However, highway pavement research has generally been targeted on developing incremental solutions for local problems.

The goals in improving U.S. highways include developing materials that could enhance highway pavement performance and maintenance and restoration techniques. For example, recycling materials could reduce initial costs and increase energy savings. Research on highway pavement technologies could also help protect the environment and improve highway safety.

In this section, we briefly describe how the major participants in national highway research interact and how the federally financed research programs are organized.

The Multidimensional Highway Research Community

Among the many participants in U.S. highway research and development that we discuss below are the federal, state, and local governments, universities, and national associations and other organizations in the private sector.

The Federal Highway Administration

FHWA is responsible for national leadership and guidance in highway research, development, and technology. It funds about 83 percent of all U.S. highway research activities through the highway trust fund. It funds research through contracts with a variety of agencies, conducts research in its laboratories at its Virginia Turner Fairbanks Highway Research Center, monitors the federal funds allocated to state highway agencies for research and development, and funds and promotes the dissemination and use of research results. FHWA attempts to coordinate activities in a way that avoids the duplication of research efforts, and it provides technical input regarding highway technologies to the states. It helps maintain a cooperative relationship, or "partnership," between the states and the federal government in the federal-aid highway program.

Other Federal Agencies

Other federal agencies that contribute to highway research include the National Highway and Transportation Safety Administration, the Urban Mass Transit Administration, the Federal Aviation Administration, the U.S. Forest Service, the National Bureau of Standards, the U.S. Army Corps of Engineers, and other Department of Defense organizations.

The States

According to FHWA, almost all the states—95 percent—conducted non-federally funded research in 1982, an increase from about 75 percent of the states in 1973. Some states conduct their own research, while others provide funds to sponsor university research. FHWA estimates that state research expenditures average about 0.25 percent of the state highway agencies' budgets and that the states provide approximately $10 million per year for independent highway research and $7 million in matching funds for federally assisted research efforts.

National Associations

AASHTO and other national associations establish committees that coordinate research activities in specific technical areas to promote the establishment of national standards. Some national associations from private industry, such as the Portland Cement Association and the Asphalt Institute, also sponsor and conduct research in their special fields of interest.

The Transportation Research Board

TRB assists in publishing and disseminating National Research Council results. FHWA funds TRB's Transportation Research Information Service, which is a computer-based information storage and retrieval system consisting of abstracts of published works and summaries of research projects in progress. With FHWA and AASHTO, TRB also manages the National Cooperative Highway Research Program (NCHRP), briefly described within the next section.

The Nationally Coordinated Program

The Nationally Coordinated Program (NCP) is an administrative structure adopted in fiscal 1987 to manage and coordinate all levels of highway research, development, and technology transfer. It replaces FHWA's Federally Coordinated Program, which since 1971 had responded to

- FHWA organizational changes,
- the formation of the Strategic Highway Research Program (SHRP), and
- the transition from interstate construction to restoring and reconstructing existing facilities.

NCP allows the coordination and cataloging of federally supported work within nine program categories: highway safety, traffic operations, pavements, structures, materials and operations, research and development management and coordination, planning and policy, motor carrier transportation, and other activities. The last three categories are new additions to assist FHWA in program planning, in management and coordination, and in setting priorities and budgeting. FHWA is currently reprogramming its highway technology information management system to track research and technology transfer activities in these nine categories.

FHWA will not establish priorities for all work in NCP but has designated emphasis areas for FHWA contract and staff efforts. An official told us that FHWA identified about 14 high-priority national program areas within the nine categories for fiscal year 1987. NCP is designed to promote the interaction of researchers. States, groups of states, or SHRP could lead research activities in various categories.

Highway Planning and Research

Federal research on highways began in 1893 in the office of road inquiry of the U.S. Department of Agriculture. The primary mission of this office was to investigate the best methods of roadmaking and to assist in disseminating this information. Later, the Hayden-Cartright Act of 1934 laid the foundation for federal aid to states for highway planning and research. Under this act, up to 1.5 percent of the highway funds apportioned to a state could be used for "surveys, plans, and engineering investigations." The Federal-Aid Highway Act of 1944 added the term "research" to this. The states could now use their 1.5 percent for a variety of research purposes. Unused portions reverted to construction. Under the Federal-Aid Highway Act of 1962, the 1.5 percent is restricted to planning and research, although amendments in 1963 expanded the law to include "development" under planning and research.

Under the 1987 act, each state may use 1.5 percent of its federal apportionment for planning and research. State population and road mileage are factors in the formulas used to determine a state's total apportionment, which may be used for engineering and economic surveys and investigations; for planning future highway programs and their financing; for studies of the economy, safety, and convenience of highway usage and their regulation and taxation; and for research and development necessary in planning, designing, constructing, and maintaining highways and highway systems and regulating and taxing their use.

In fiscal year 1985, the planning and research apportionment for research—including $7 million of state matching funds—totaled $45 million, which amounted to about 45 percent of the total U.S. highway research program of $100 million financed by the highway trust fund. Designated funds must be matched by the states according to a ratio established in federal law. Generally, the federal government supplies 85 percent and the states provide 15 percent.

According to FHWA, state research efforts could expand during the next few years. The Surface Transportation Assistance Act of 1982 increased the gasoline tax and broadened the funding base for each state's federal-aid apportionment, proportionally increasing the money available for research. Increased resources are available for planning and research in highway program funding levels legislated in the 1982 and 1987 highway acts, and eligibility for the 1.5-percent planning and research funds has broadened. But fewer federal resources were available in fiscal year 1987 than in 1986—$152 million, down from $176 million.

The states have discretionary authority to divide their funds between planning and research. Therefore, the amount of federal funds made available for research activities varies according to each state's own priorities and decisions. FHWA indicates that in fiscal year 1985, the states directed an average of 20 percent of their planning and research funds toward research, leaving about 80 percent of the money for planning purposes. As shown in table 3.1, the planning and research apportionments to the states totaled almost $177 million in fiscal year 1986. The average was about $3.5 million, but 19 states received more than the average. California, New York, and Texas received the most.

An FHWA official told us that the states planned to spend about 25 percent of their planning and research funds on research in fiscal year 1987. According to FHWA, 18 states devoted more than 20 percent of their funds to research (Texas spent up to 72 percent of its federal apportionment on research activities). In contrast, 10 states spent less than 10 percent of their planning and research funds on research.

The state highway agencies decide what research to conduct and whether to focus on local or national problems or a mixture of the two. Their decisions vary greatly, and each state approaches highway research differently. For example, some states conduct their own laboratory and field research, some states work closely with universities, and others issue contracts for research services.

Table 3.1: The States' Apportionments for Highway Planning and Research in Fiscal Years 1984-86

State	1984	1985	1986
Alabama	$3,536,973	$3,883,159	$3,615,704
Alaska	2,231,511	2,389,712	2,418,908
Arizona	2,367,959	2,617,427	2,615,258
Arkansas	1,744,018	1,849,684	1,818,284
California	13,663,403	13,894,192	14,165,079
Colorado	2,649,350	2,863,646	2,899,171
Connecticut	2,532,490	2,661,123	2,889,591
Delaware	766,161	814,388	822,080
District of Columbia	797,242	849,911	887,187
Florida	6,580,595	7,393,879	8,035,472
Georgia	5,081,609	5,367,104	4,983,214
Hawaii	1,768,043	1,986,363	1,866,960
Idaho	1,181,930	1,327,758	1,363,026
Illinois	4,820,244	4,819,066	4,958,521
Indiana	2,907,861	3,055,961	2,996,058
Iowa	2,147,196	2,282,545	2,353,118
Kansas	2,127,018	2,306,995	2,376,650
Kentucky	3,201,706	3,142,958	3,287,339
Louisiana	4,677,983	4,813,522	5,089,772
Maine	909,940	940,349	933,454
Maryland	3,618,429	3,286,867	3,260,786
Massachusetts	3,912,855	4,677,035	4,435,447
Michigan	4,304,631	4,651,122	4,884,942
Minnesota	3,114,183	3,357,580	3,674,840
Mississippi	1,948,728	2,073,042	2,008,175
Missouri	3,653,321	3,736,987	3,898,677
Montana	1,609,280	1,784,169	1,743,774
Nebraska	1,533,233	1,669,842	1,685,519
Nevada	1,074,942	1,156,513	1,173,199
New Hampshire	844,230	913,453	926,692
New Jersey	4,250,111	4,774,905	5,096,561
New Mexico	1,489,851	1,631,294	1,700,621
New York	9,912,635	11,070,092	12,026,585
North Carolina	3,530,525	3,425,021	3,641,489
North Dakota	1,111,619	1,192,432	1,200,721
Ohio	5,174,283	5,727,883	5,455,770
Oklahoma	2,337,070	2,378,979	2,397,335
Oregon	1,971,886	1,996,362	2,023,064
Pennsylvania	7,873,727	8,719,159	7,949,813
Rhode Island	772,380	845,159	850,802

(continued)

State	1984	1985	1986
South Carolina	2,256,601	2,338,586	2,336,410
South Dakota	1,189,496	1,289,554	1,326,141
Tennessee	3,181,438	3,274,907	3,535,919
Texas	9,728,203	10,323,361	10,611,710
Utah	1,921,028	2,247,533	2,194,792
Vermont	821,222	886,277	889,353
Virginia	4,422,734	4,687,158	4,979,566
Washington	4,505,468	4,660,140	4,817,253
West Virginia	2,221,389	2,123,357	1,661,757
Wisconsin	2,407,954	2,561,464	2,588,704
Wyoming	1,221,605	1,328,189	1,348,904
Total	**$163,608,289**	**$174,048,164**	**$176,690,167**
Average	**$3,208,006**	**$3,412,709**	**$3,464,513**

When there is widespread regional interest regarding a significant problem, the states conduct research studies of major importance in conjunction with other states, FHWA, universities, private contractors, and the like. These studies, called "pooled fund projects," are part of the planning and research program, whose funds they may use with no state matching funds required, once the FHWA administrator has approved a project.

FHWA needs information about accomplishments and planned work to coordinate national research efforts. It asks the states to submit progress reports twice a year on all studies using planning and research funds. At the conclusion of a study, FHWA requires final reports. These are intended to document the studies in an adequate and timely manner and to encourage the distribution of research information. However, FHWA officials informed us that, in practice, there is little standardization in how the states present their reports. An FHWA official told us that this lack of uniformity can detract from the usefulness of the information.

The National Cooperative Highway Research Program

Under NCHRP, initiated in 1962, the states voluntarily pool 4.5 percent of their total federal planning and research allocation each year to finance research activities. In fiscal year 1985, the states pooled $8 million, which amounted to about 8 percent of the U.S. highway research program.

NCHRP research is contractual and structured to respond to the needs of state highway agencies. The first step in conducting research is the submission of statements by the states, AASHTO committees, and FHWA that describe areas in which states have problems and would like research projects to develop solutions. Universities, private researchers, and state highway agencies may submit proposals for NCHRP projects. About 160 problem statements were submitted in fiscal year 1986. According to NCHRP, each year's program consists of 7 to 10 new problems, on the average, in addition to progress on a similar number of projects funded in earlier years.

NCHRP sends out project statements describing each problem's specific research objectives. The topics may range through eight fields: administration (economics, law, and finance), soils and geology (testing and instrumentation, properties, and mechanics and foundations), transportation planning (forecasting and "impact" analysis), design (pavements, bridges, general design, roadside development, and vehicle barrier systems), materials and construction (specifications, procedures and practices, and general, bituminous, and concrete materials), maintenance (snow and ice control, equipment, and maintenance of ways and structures), traffic (operations and control, illumination and visibility, traffic planning, and safety), and special projects.

FHWA is responsible for the highway trust fund money used to finance NCHRP studies. FHWA staff comment on all the problem statements, supplying information about the need for the research and on whether projects duplicate research in progress. They review a project's contents and the selection of its contractors. AASHTO and the participating states select programs and their composition. An AASHTO executive committee vote determines which NCHRP projects are funded each year. AASHTO represents the states' interests in formulating the annual programs, approving the selection of contractors, and monitoring the studies. TRB administers the research program, requiring final reports for all projects.

Administrative Contract and Staff Research Programs

The administrative contract and staff research programs are funded through the highway trust fund as part of FHWA's budget. The administrative contract program allows FHWA to initiate contracts with state highway agencies, universities, businesses, consultants, and others for research and development efforts, and it includes support for on-site contractors at FHWA's Turner Fairbanks Highway Research Center. Frequently this research requires an operating highway or highway system for experimentation, testing, and evaluation, and state highway agencies may offer one as a resource.

FHWA publishes its contracting plans in the Federal Register and advertises proposed contract procurements regularly in Commerce Business Daily. Most contracts are competitive. They may be awarded to states with 100 percent federal funding or on a cost-sharing basis. Funding was $19.2 million in fiscal year 1985.

Staff research funding allows FHWA to conduct research such as that performed by FHWA staff at the Turner Fairbanks Highway Research Center, which is geared toward highway technologies not under the control of any one company. FHWA conducts highway research on a broad range, from scientifically investigating basic highway-related technologies to developing and testing new devices, methods, and technologies for construction, maintenance, or the control of traffic operations. Staff studies may include continuing efforts in major research areas as well as quick responses to operational problems. This program also provides staff for planning, administering, and monitoring research activities by other organizations using federal funds. In fiscal year 1985, the staff research program received $2.5 million.

The Strategic Highway Research Program

The Surface Transportation and Uniform Relocation Assistance Act of 1987 established SHRP as a unit of the National Research Council to carry out research, development, and technology transfer activities strategically important to the national highway transportation system. SHRP is principally directed toward maintaining the U.S. highway and bridge infrastructure and is expected to produce basic research and performance information to address current limitations in highway research. Research results are expected to become available over a 5- to 20-year period.

The 1987 act sets aside amounts not to exceed 0.25 percent of the states' total authorizations for federal-aid highway funds for SHRP for fiscal years 1987 through 1991. FHWA anticipates that this will be approximately $30 million per year for this 5-year period. An official told us that FHWA will oversee these federal funds and approve SHRP studies and proposals.

FHWA included SHRP in its NCP to try to incorporate the changes in resource priorities and accelerated study periods that SHRP brings to highway research and development activities. SHRP will concentrate on developing innovative research and new technologies to solve critical pavement and structural problems in the six areas described below.

Asphalt

SHRP's research in asphalt is intended to identify and define the chemical and physical properties of asphalt and asphaltic concretes. The results could be used to develop specifications, tests, and construction procedures to improve pavement performance. Because asphalt is one of the most common components of highway construction, improving asphalt pavements could provide considerable cost savings.

Long-Term Pavement Performance

The United States has not systematically studied highway performance since 1960, when AASHTO conducted a large-scale test of 836 sections of asphalt and concrete roads. SHRP's 5- to 20-year program is expected to provide information on the long-term performance of various pavement structures given different maintenance programs, traffic loads, climatic factors, and subgrade soils. The objective of this research is to increase pavement life by developing a data base on pavement performance over a wide range of conditions to enhance testing or comparisons of paving materials and assist in answering questions such as

- How does climate affect pavement performance?
- How does highway pavement perform under various traffic conditions?
- How do these two factors interact and what methods can be used to determine the associated costs?
- How do maintenance and repair programs affect pavement performance?

Maintenance Cost Effectiveness

This study will attempt to increase the cost effectiveness of maintenance through developing administrative and technological improvements, including

- management information systems that provide capabilities for developing budgets, administering programs, and allocating resources and
- technological improvements in equipment, materials, and processes that will increase productivity.

Protection of Concrete Bridge Components

This effort has two main goals. One is preventing the deterioration of existing bridge concrete already exposed to salt for several seasons and badly contaminated with chlorides. The other is the protection of new and uncontaminated concrete. The key problem, according to SHRP, is the need to develop economically feasible methods of saving the thousands of bridge decks built before the use of present-day protective systems.

Highway Cement and Concrete

This program's primary goals are to increase understanding of the chemistry of cement hydration (the chemical effects of combining cement with water), the properties of concrete, and the performance of concrete in highway environments. SHRP will attempt to address these areas to improve the economy, versatility, and durability of concrete in highway pavements and structures.

Chemical Control of Snow and Ice

Research will be directed at improving highway snow and ice control programs by exploring improvements in mechanical, thermal, and other removal techniques and producing environmentally safe alternative chemicals. This project hopes to avoid bridge, pavement, and vehicle deterioration as well as other adverse environmental effects, by reducing the dependence on chlorides for snow and ice control.

Technology Transfer

The Federal Highway Administration defines technology transfer as "the process by which existing research and development findings and other new technologies are transferred operationally into useful processes, products, or programs that fulfill existing or potential public or private needs." The nine categories of FHWA's Nationally Coordinated Program include technology transfer activities, and technology transfer specialists are assigned responsibilities for each category. They report, directly or indirectly, to FHWA's associate administrator for research, development, and technology, and their primary responsibilities for national technology transfer activities are to

- serve as a communications link between the various sources of new technology and the state and local agencies that can apply the technology in daily operations and
- encourage organizational structures and personnel assignments throughout FHWA and state highway agencies that will help transmit available technology from any source to actual field use.

FHWA's technology transfer centers, located at universities and state highway agencies, provide information, advice, and training about roads, bridges, and public transportation.

Office of Implementation

FHWA's office of implementation synthesizes related research findings, conducts field tests (in cooperation with state and local highway agencies), evaluates FHWA research, and translates these findings into forms suitable for broad distribution. The office also sponsors conferences, seminars, and workshops to share information on operational problems and new technology applications. It develops and disseminates information through computer programs, audiovisual presentations, written materials, and pilot training courses.

National Highway Institute

The National Highway Institute (NHI) was established in the Federal-Aid Highway Act of 1970 to develop and administer training programs for FHWA and state and local highway department employees engaged in federal-aid highway work. Working in cooperation with the state highway departments, NHI develops and presents training through short courses on various transportation topics, college courses, grants for research, and special projects. The Surface Transportation and Uniform Relocation Assistance Act of 1987 allows the states to use federal-aid funds to pay 75 percent of the cost of education and training purchased from any source, including NHI.

Rural Technical Assistance Program

The rural technical assistance program, authorized by the Department of Transportation and Related Agencies Appropriation Bill of 1982, is administered by the National Highway Institute. It provides technical assistance to state and local highway agencies regarding rural roads, bridges, and public transportation through FHWA's technology transfer centers.

Other Transfer Programs

Other technology transfer operations fall under the jurisdiction of FHWA's associate administrator for engineering and program development and are included in FHWA's Nationally Coordinated Program.

Demonstration Projects. The office of highway operations administers two technology transfer programs in the demonstration projects division, which promotes the accelerated adoption of FHWA-selected technologies. It selects research and development projects that can best be promoted through actual hands-on demonstrations, where users can examine new types of equipment, testing methods, or technologies. It conducts workshop training, seminars, and physical demonstrations that include presentations on technologies along with the technical and financial assistance that will incorporate the technology into an actual construction project.

Experimental Projects. The experimental projects program is designed to encourage the construction and evaluation of promising new or innovative technologies that have a limited performance record. It monitors the performance of experimental features that the states have incorporated in highway construction projects to determine whether the experimental technology is suitable for regular use on highways. The results of these field evaluations are published annually in The Experimental Projects Tabulation.

How Research Can Help Meet Highway Needs

Numerous opportunities for improving highway research efforts exist. Adjusting current practices to take advantage of available opportunities could help increase the service life of the nation's highways. Many factors influence the performance of highway technologies, including materials, construction and maintenance practices, traffic loads, and soils, water, and frost. However, fundamental questions regarding their interaction and effects have to be asked. According to various highway research authorities, each section of highway is a unique system.

The research on such systems is fragmented, and some research evaluation reports are either so site-specific or written in such highly technical language that others cannot use the information. Moreover, the funding commitment has been low. Highway research represented 0.3 percent of all highway expenditures in 1985. In contrast, SHRP estimates that high-technology industries (such as semiconductors and aerospace) spend about 6 percent of their gross sales revenues on research. Even low-technology industries (such as building materials, paper, and steel) spend an average of 1.4 percent of their sales on research.

In this section, we present information about highway research goals and about the physical and institutional conditions that make it difficult to adopt promising highway research findings.

Goals for Highway Research

Current traffic demands are placing a heavy burden on the highway system, and the number of roads reaching the end of their design life and requiring repair is increasing. According to the American Transportation Advisory Council, travel on U.S. highways is projected to increase at an annual rate of 2.7 percent. FHWA projects that by the year 2000, approximately 41,000 miles of interstate highways, 334,000 miles of arterials, and 636,000 miles of collectors will require capital improvements to maintain serviceability. Meanwhile, maintenance costs increased 66 percent from 1977 through 1983. According to information from SHRP, maintaining the nation's state and local road network requires more than one third of the total highway budget, and this share is increasing.

Despite this spending, highways are continuing to deteriorate, indicating the need for research to develop effective maintenance and repair technologies. Keeping highways in good repair is important, because the overall cost of using roads increases as their condition deteriorates. Vehicle maintenance costs rise as roads become rougher, travel times lengthen at lower speeds, and travel distances may grow as drivers try to avoid particularly bad stretches of road. Accidents, too, may increase. An FHWA study found that operating costs on a road in poor condition may be 20 to 36 percent higher than on a road in good condition.

Methods, equipment, and materials have not changed significantly in recent years, although both the mileage and traffic volume of the highway system have increased. New products that improve highway service and reduce costs are needed. Research on how to improve highway rehabilitation techniques and materials could assist in developing cost effective methods of preserving the highway system. Research and decisions about the use of highway pavement technologies will play an important role in determining how current and future highway needs are met. In the area of highway pavement technologies, state highway agencies need not only new materials but also new procedures and techniques. For example, research shows that increasing the depth of a pavement section enhances its load-bearing capacity. Research on innovative materials might permit building better roads rather than simply building heavier roads.

FHWA has proposed four goals for highway research efforts:

1. Research can help increase highway performance, so that highways can efficiently provide reliable service in moving people and goods.

2. Highway pavement research can enhance safety by providing adequate protection for vehicles (such as skid-resistant surfaces).

3. Research can help improve the compatibility of the highway system with its environment by developing technologies that can help improve air quality, reduce noise, and protect water quality.

4. As the existing highway system wears out, research can help reduce maintenance and restoration costs. For example, recycling, using new materials, or improving maintenance and rehabilitation practices could increase cost effectiveness. In addition, long-term savings can result from using highways and structures that have minimal life-cycle costs, if higher initial costs are offset by lower maintenance and operating costs and a longer highway service life.

In addition, we believe that potential benefits from highway pavement research include

- more efficient research operations across currently fragmented activities;
- useful innovations in highway pavement technologies (including products, materials, and techniques);
- greater knowledge about highway performance and materials, as well as their interaction with the environment; and
- effective strategic planning for research at the community, state, and national levels.

In our next report, we intend to focus on how the states conduct their research activities, including how research on highways is implemented and the criteria used for choosing between alternative highway technologies.

The Effect of Site-Specific Conditions

In one pavement section, a technology may work well. Under different circumstances of climate and stress, the same technology may not work well at all. Engineers have extensive alternatives to choose from throughout every stage of highway design and construction, and many different factors are involved, as we discuss below.

Construction and Maintenance Practices

The performance of any one stretch of pavement depends on quality control and construction practices specific to that pavement. Moreover, applying a highway pavement technology incorrectly may result in premature pavement failure.

Materials

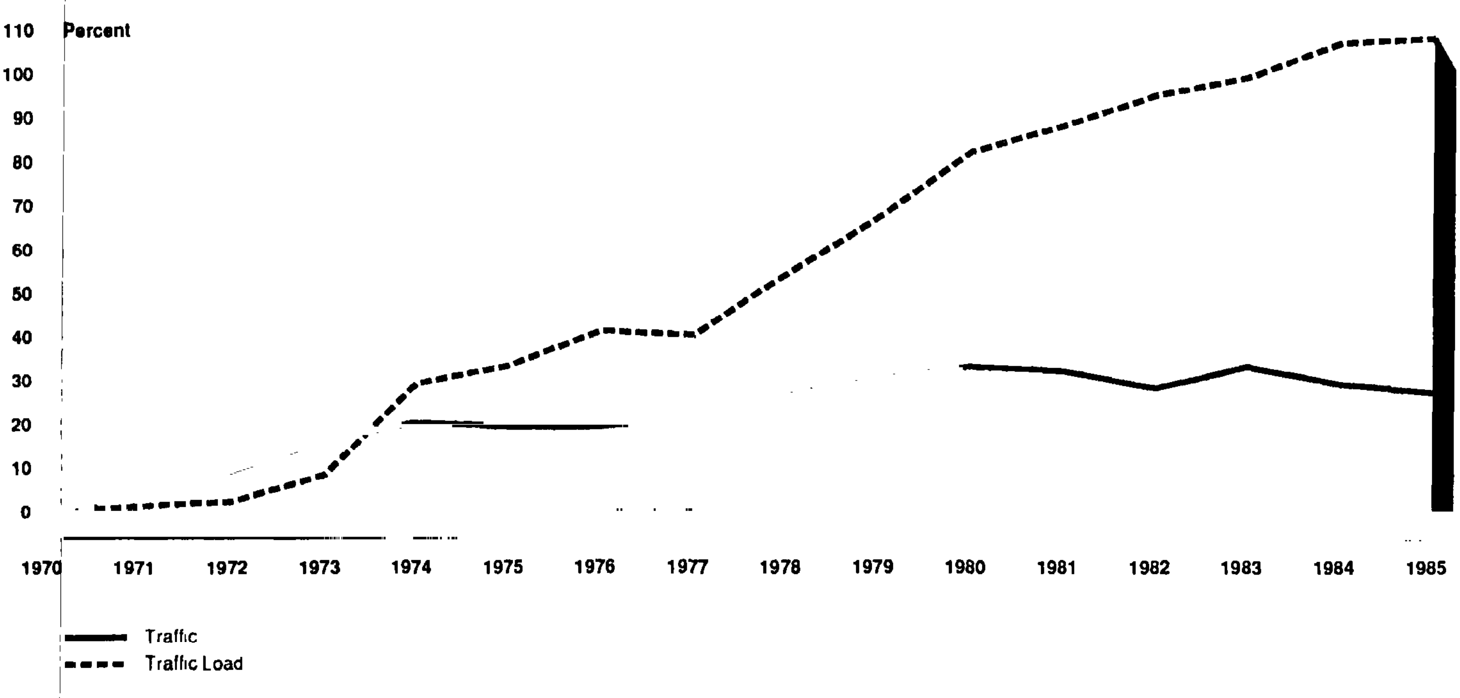
The thousands of different products, materials, equipment, methods, and so forth can be used in different ways, and performance varies, depending on the situation. Occasionally, product formulations change without a change in the product's name, or the same formulation may appear under different names. The complexity of materials used in pavements is well illustrated by asphalt pavements. It is uncertain how the many asphalt additives on the market today will react with other materials. Variations in asphalt pavement performance may result from shifts in sources of crude oil, new refining processes, mixing techniques, construction practices, aggregates, pavement design, and other factors.

FHWA, AASHTO, and the states cooperate in an effort to share information about new product evaluations. They issue a special product evaluation list that provides information about products state highway agencies have evaluated in some manner. These products may include manufactured products, materials, and applications of specialized processes. Approximately 35 states have submitted evaluations of more than 6,500 products for the current listing. However, FHWA and AASHTO caution that the information they present is not an endorsement or a rejection of the products, stating that no general conclusions should be drawn from the list about the overall suitability or unacceptability of products for their intended use.

Traffic Load

The amount of traffic on a road affects pavement life. Heavier trucks and new high-pressure tires increase the rate of pavement deterioration. For example, a major structural distress, "alligator cracking," a series of

Figure 4.1: Daily Traffic and Traffic Loads on Rural Interstate Highways 1970-85[a]



[a] Data were based on a 3-year moving average and were measured at truck weight sites. The number of vehicles in 1970 was 11,637, and the estimated daily axle load was 2,079.

Source: Federal Highway Administration, Highway Statistics 1985 (Washington, D.C.: U.S. Government Printing Office, 1985), p. 181.

interconnected cracks caused by the fatigue of an asphalt pavement surface, occurs in areas that are subject to heavy traffic. Assessments of the damage attributable to trucks is quite varied, ranging from the 10 to 20 percent estimated by FHWA to the 90 percent estimated by the California Department of Transportation.

As shown in figure 4.1, total daily traffic has hardly grown over the last 10-year period. In contrast, the daily load on the pavements has nearly quadrupled. Compounding this increase in loading is the problem that a wheel's load today is transmitted to the pavement by narrow, high-pressure tires. Some state highway officials told us that high-pressure tires distribute truck weight in a concentrated manner that is beyond most pavement design allowances.

Interstate highways are designed to carry a number of equivalent truck loads, or the estimated "daily axle loads," forecasted to use the highway over a 20-year period. Provisions in the Surface Transportation Assistance Act of 1982 allowed heavier loads and larger trucks to use the interstate system that were probably not anticipated in the original forecasts. If the forecasts underestimated the post-1982 traffic loads, highways may not provide the 20 years of service life expected of them.

Soil

Soil varies considerably in the amount of support it provides, how well it may be compacted, and how much moisture it allows into a pavement structure. The load-carrying ability of the soil, which forms the subgrade for pavement, affects highways in important ways. The type of soil and the stability of the soil supporting the highway structure are important variables in determining whether to use a particular technology. For example, Pennsylvania relies on load transfer devices in concrete pavement joints because of its relatively unstable soils, while California does not use load transfer devices because the soil there is stable. The inherent qualities of soil in various areas are not uniform, and they vary under the influence of different weather conditions.

Climate and Water

Temperature can stress asphalt concrete in several ways. For example, "bleeding" occurs when asphalt expands onto the surface of the pavement during hot weather. This process is not reversible in cold weather, so this asphalt film remains on the surface, reducing the pavement's skid resistance. Temperature, as well as the freezing and thawing of roadbed soil, also affects the contraction and expansion of Portland cement concrete. Thawing cycles can damage pavements, depending on the rapidity of the thaw and the drainage capabilities of the pavement system. For example, durability, or "D," cracking, caused by the expansive pressures of the freeze-thaw cycle, is a series of cracks that may appear on a concrete slab surface and eventually lead to its disintegration.

Water problems are numerous and complex. Water may enter a pavement structure in many ways, as groundwater or through cracks, joints, or pavement infiltration. Officials in California believe the most important reason for pavement deterioration is the presence of water and the lack of proper drainage. Both flexible and rigid pavements have drainage problems. Water trapped within a pavement may affect a highway by

- reducing the strength of the materials or roadbed soils;
- stripping the asphalt binding off the aggregate, so that the highway surface may disintegrate or wear off and become rough and pitted;
- creating pumping, or the movement of materials by water pressure beneath a slab when it is deflected under a heavy, moving wheel load, so that water and silt, sand, and clay are forced out of a joint or crack as trucks pass over the surface. The remaining materials left under the slab are loosely compacted, with some voids that result in a loss of support for the highway.

When inadequate drainage is compounded with the stress of truck loading, pavement deterioration is accelerated. The highway industry has not determined all the effects of climate and traffic loads on pavements, and it is difficult to determine a priori how new technologies will affect highway performance.

A survey of pavement condition is generally necessary before a rehabilitation project can be evaluated and designed. The type of distress in the pavement has to be identified in order to select corrective measures. The causes of distress are not always easily identified and may consist of a combination of problems. Applying maintenance and rehabilitation techniques is complex, because engineers must ensure that new portions of pavement are structurally compatible with the original pavement and have a comparable remaining life.

When correcting for distress, engineers must repair the cause of the pavement's deterioration and prevent it from recurring. For example, if water under a pavement has washed the supporting subgrade away, engineers must seal the joints and other pavement cracks, besides filling the void, in order to prevent future water damage.

Traffic conditions and inconvenience to travelers also affect decisions regarding pavement rehabilitation procedures. Some rehabilitation methods allow partial traffic flow, whereas others require closing lanes. Such problems are site specific and must be resolved case by case.

Factors That May Prevent Innovation

Early in our review, we obtained information about potential organizational and economic barriers to innovative research on highway pavement technologies. According to SHRP, state and local highway agencies face budgetary pressures and electoral priorities that favor short-term, highly visible projects rather than long-term needs, such as research. Because it is difficult to measure the value of research, or to compare research costs with the costs of allowing existing conditions to continue, it is also difficult to base the allocation of funds to research on cost-benefit considerations. Public agencies may have difficulties producing basic research because it carries with it the risk of low return, which might not be accepted by taxpayers.

An FHWA official told us that some states are conservative in their approach to adopting highway pavement technologies, because they want to see that a technology will probably work in their state before trying it. There are costs and risks associated with adopting a technology, such as the cost to correct problems caused by inappropriate use of products or concepts. The states may conduct field trials to provide evidence of a technology's performance and usefulness. Field trials demonstrate technologies by incorporating products or materials in a highway facility or by using processes and equipment in maintenance, construction, or highway operations. Introducing innovative technologies may require highway agencies to consider changes in longstanding operational practices.

The deterioration and maintenance of the national infrastructure is a complex problem. It involves not only technical issues but also the interaction of a variety of complex institutional factors. Low-bid procurement practices, prescriptive performance specifications, and local materials exemplify these factors but are not necessarily the most important ones.

Low-Bid Procurement Practices

A technology that is economical in the long run may be rejected because its initial construction cost is higher than that of a competing technology. In other words, first-cost considerations may outweigh the lower life-cycle costs—including maintenance and rehabilitation costs, anticipated service life, and the salvage value—of a given technology. According to an official of the Portland Cement Association, the "low first-cost" concept is a serious deterrent to new product development, quality improvement, and innovative technology.

Local Materials and Services

Some states require that highway agencies use local suppliers and services. The high cost of transporting bulky, low-value construction materials such as sand and gravel is one reason the states buy local products. However, in some cases, local materials may be inferior and may not perform the best. A professor of civil engineering in Illinois told us that local aggregate is not suitable for use on highways in several midwestern states, including Illinois, Iowa, Kansas, Missouri, and Nebraska.

The large number of diverse local suppliers is reflected in the asphalt cement industry, where highway construction is the dominant user. Mixing and placing asphalt pavements involves, for example, construction contractors; producers of sand, gravel, and crushed stone; asphalt-mixing plant operators; equipment manufacturers; and refiners. According to a consultant who helped plan SHRP, this diversity presents a challenge in developing a consistent way of evaluating the performance of new products and materials.

Rigid Specifications and Standards

Highway contracts use detailed product specifications in an attempt to ensure that contractors provide acceptable products. However, a new technology with superior characteristics may fail to meet existing specification criteria and be rejected. According to the Arizona Department of Transportation, for example, rigid adherence to inappropriate standards can add 40 percent to project costs. Standards that are more performance-oriented could encourage more private-sector highway research. In some instances, developing performance-based specifications could require new research.

Voluminous Information

Information about research on highway technologies is dispersed among many publications. According to highway officials from Texas, information, concepts, and products are introduced at a rate far exceeding the highway industry's capacity to evaluate and assimilate the innovations they represent. Fragmentation among the great number of agencies involved in research activities as well as the diversity and volume of information available provide a strong potential for confusion.

Lack of Standardized Reporting

Although states, universities, and counties share the results of their research and evaluations, meaningful comparison is sometimes impaired because not all relevant conditions are explored and because available studies used different measurement techniques, recorded different characteristics of a process, and so forth. The types of data collected sometimes vary, not only from state to state but also from project to project within a state.

Diversity

State highway agencies are diverse. Each has its own organizational structure, political climate, public priorities, and historical perspectives. This diversity may contribute new ideas and approaches to highway research. However, highway and transportation department interest in new technologies may cross organizational lines (material, construction, maintenance, and so on), which could also increase the complexity of the research and evaluation process. Historical perspectives within an agency might inhibit the acceptance of innovative technologies that require a change from past practices.

Summary

The physical condition of the nation's highways is a major policy concern. According to the Transportation Research Board, the deferral of highway maintenance and rehabilitation work has accelerated highway deterioration. Expensive remedial treatments are required to repair a road that has deteriorated without the necessary maintenance. Traffic loads greater than expected in some states have caused road damage and resulted in the need for rehabilitation.

The interaction of various factors affecting pavement performance is complex and in some instances unknown. Some of the factors influencing pavement life include construction and maintenance practices, support provided by the underlying soil, the quality of the materials used, the distribution and weight of traffic loads, and climatic and other environmental conditions. The degree to which each of these factors influences highway pavements is often affected by their interaction.

The U.S. highway system's operation is divided between thousands of federal, state, county, city, and private organizations. While these units of government have innumerable common concerns, highway performance problems are specific to each site, so that research often focuses on current local problems. Information from NCHRP indicates that the exchange of research information is a valuable tool for locating useful highway technologies and avoiding the duplication of evaluation efforts. Monitoring, evaluating, and reporting research results can make information available to others who might want to try a technology.

State highway agencies must make decisions about using the various highway pavement technologies in the face of the often contradictory goals of improving highway performance and cutting costs. Research and technological innovation could help bridge the gap between the scope of programs for rebuilding and replacing public highway facilities and the ability to finance them.

According to NCHRP, current changes have led several states to realize the necessity of reevaluating their research programs, and it seems that more will also soon realize this necessity. Changes in highway management, funding and funding sources, and attitudes toward research are now occurring. Reviews, evaluations, and adjustments in research organization structures and operations in state highway and transportation agencies appear to be especially pertinent at this time.

Given the complexity of developing an effective strategy for learning about and implementing technologies, it is necessary to determine how the states arrive at their decisions. Many new products are proposed for use to state highway agencies each year. The states attempt to evaluate each highway technology before accepting it to ensure that products will fill a need, be cost effective, and not produce undesirable side effects.

In our next report, we intend to examine the processes the states use for choosing highway pavement technologies and the relationship of those processes to the states' experiences with specific highway pavement technologies. We hope to answer the following policy question: What are the principal factors that determine the adoption of or lead to the rejection of competing highway pavement technologies, and to what extent are decisions based on cost or performance criteria or both?

Our staff is currently analyzing responses to a questionnaire we sent to the 50 states and the District of Columbia, while also reviewing evaluations the states submitted regarding field tests of six selected technologies. This effort is intended to provide a detailed portrait of

- how the states decide to adopt or reject technologies,
- to what extent the states use selected technologies,
- the criteria the states use in adopting selected technologies, and
- the barriers that prevent the states from adopting selected technologies.

Request Letter

Committee on Public Works and Transportation
One Hundredth Congress
U.S. House of Representatives
Room 2165, Rayburn House Office Building
Washington, DC 20515

TELEPHONE: AREA CODE 202, 225-4472

B-376 Rayburn Building
Washington, D.C. 20515
June 2, 1987

Honorable Charles A. Bowsher
Comptroller General of the United States
U.S. General Accounting Office
441 G Street, N.W.
Washington, D.C. 20548

Dear Mr. Bowsher:

As you know, the Subcommittee on Investigations and Oversight is interested in cost effective approaches that could assist in maintaining and rehabilitating our highways. In response to this interest, your Program Evaluation and Methodology Division (PEMD) is evaluating how states decide to adopt or reject highway pavement technologies. The PEMD has begun a survey effort, in conjuction with a review of state evaluations, to answer the questions posed in our request of December 23, 1985.

We understand that during the initial stages of the review your staff has collected a substantial amount of background information regarding the highway system and how research efforts to develop highway technologies are currently structured. This background information also contains information on the role research can play in meeting the needs for highway pavement technologies to improve highway performance or reduce costs.

While we await the returns of the questionnaire, their subsequent analysis, and the completion of your evaluation review, I would like to suggest that you break out the description of the highway system and structure for conducting research as a separate and more immediate product. The early receipt of this information will assist the subcommittee staff in setting its agenda for the coming year.

Honorable Charles A. Bowsher
June 1, 1987
Page Two

If this proposal is acceptable, I would request that your staff coordinate their efforts with our staff engineer, Richard Tearle, at 225-3274.

Sincerely,

James L. Oberstar

James L. Oberstar
Chairman
Subcommittee on
Investigations and Oversight

JLO/tjm

Glossary

Aggregate	The sand, gravel, and pebbles added to cement in making concrete.
Aggregate Interlock	The rock particles of varying sizes in asphalt mix provide a mixed distribution of large and small particles that "interlock" rather than moving around in the asphalt mix.
Arterial	A highway that moves large numbers of vehicles quickly from one place to another. Arterials are characterized by long-distance travel, high volumes, and higher speeds than other roads.
Asphalt	A brown or black tarlike substance (a variety of bitumen found in a natural state or obtained by evaporating petroleum) mixed with sand or gravel and used for paving.
Base Course	In pavement structure, the layer or layers of material placed on a subgrade or subbase to support a surface course. See also Pavement structure.
Cement	A powdered substance made of burned lime and clay and mixed with water, sand, and gravel to make concrete.
Cohesion	The basic ability of asphalt mix to hold asphalt pavement together.
Collector	A route that gathers vehicles from local roads and funnels them into arterials.
Concrete	Sand and gravel bonded together with cement into a hard, compact substance that hardens like stone and is used in making road and bridge surfaces.
Interstate Highway System	The highway system authorized by the Congress in 1944 as part of the arterial system that connects the nation's principal metropolitan areas, cities, and industrial centers as directly as possible. Interstate highways

serve the national defense and connect at suitable border points with routes of continental importance.

Local Road	A road that provides access to farms and other rural resources or to urban businesses and residences. People usually travel short distances on local roads, which are characterized by low speeds and low volumes, compared to arterials.
Particle Friction	The friction associated with rough surface particles in asphalt mix, which have less tendency than smooth particles to move around within the mix.
Pavement Structure	The combination of subgrade or subbase, base course, and surface course placed in that order on a roadbed to support the traffic load and distribute it to the roadbed.
Primary Road	A road, classified as an arterial, that consists of interconnected miles of rural routes and their urban extensions. Primary roads are usually U.S.-numbered roads—U.S.1, for example—and are similar in character to interstate routes. Federal assistance for the primary highway system dates back to 1916.
Reconstruction	Removing and replacing a defective pavement.
Rehabilitation	Laying down additional surfacing material or other work necessary to return an existing roadway, including shoulders, to structural or functional adequacy. This could include the complete removal and replacement of the pavement structure.
Restoration	Returning an existing pavement structure to a suitable condition without the immediate placement of an overlay, as in rehabilitation.
Resurfacing	Adding a layer or layers to pavement to provide additional structure or improve service.

Roadbed	The graded portion of a highway within top and side slopes prepared as a foundation for the pavement structure and shoulder. The roadbed is below the subgrade, and its preparation affects the support of the pavement structure. See also Pavement structure.
Secondary Road	A rural route classified as a major collector, such as farm-to-market roads and county and local roads, including the more important intra-county routes. Secondary roads, unlike roads in the primary system, do not form an interconnected network of highways. Instead, they are collectors of traffic, funneling onto and off the state arterial network.
Subbase	In pavement structure, the top surface immediately above the subgrade and below the base course. See also Pavement structure.
Subgrade	In pavement structure, the surface immediately above the roadbed and below the subbase. See also Pavement structure.
Surface Course	One or more of the upper layers of a pavement structure designed to accommodate the traffic load. The topmost layer is sometimes called the "wearing course" and is usually made of asphalt or concrete. See also Pavement structure.

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