Executive Summary

INTRODUCTION

At present state transportation agencies have a unique opportunity to make major improvements in the ways they build, maintain, and operate highways. Because of the infrastructure crisis, the public has awakened to its stake in the highway network. Over the years Americans have invested an astronomical $1 trillion in their highway system and are just beginning to realize that without a massive infusion of funds for rehabilitation and maintenance, the system will deteriorate rapidly. But merely replacing failing facilities will not solve the problem in the long run; better products and processes are also needed, and the research to create them is long overdue.

Research for improved highways has been seriously neglected by all measures. Relative to the size of the nation's highway expenditures, spending on highway research has fallen from 0.25 percent in 1965 to 0.15 percent in 1982. This 0.15 percent is far smaller than the research commitment of virtually all other industries: high-technology industries, such as semi-conductors or aerospace, spend 40 times as much on research; medium-technology industries such as the automobile manufacturing or chemical industries spend more than 20 times as much per dollar of sales. Even low-technology industries such as rubber, paper, and steel outspend highways by a factor of eight. Since 1973 state and federal governments have cut their highway research spending in half.

Why has not a system so crucial to everyday life, so large (4 million miles), and so expensive ($1 trillion) been supported all along by large-scale, long-term research? Chiefly because of the extreme fragmentation of the transportation industry. The U.S. highway system's operation is divided among thousands of federal, state, county, city, and private organizations.

In addition, these public agencies maintain complex contract arrangements with the private organizations that usually build or rehabilitate roads. Even routine maintenance is sometimes contracted out to private firms. Highway construction firms buy many materials locally. Both political pressure to favor local suppliers and the high cost of transporting bulky, low-value, construction materials dictate this practice. Thus an army of small, local suppliers supports many equally small, local construction firms.

This structure impedes innovation because it produces a situation in which no one organization has the resources or the incentive to undertake major research to increase facility life, reduce costs, or improve performance. Highway agencies face budgetary pressures and electoral priorities that favor short-term, highly visible projects. Further, high turnover in top management positions forces top officials to focus on visible current issues rather than on long-term functions such as research.

Despite this neglect thousands of improvements in the durability and safety of highway products have been made. For example, highway safety has been enhanced by breakaway sign posts, impact attenuators, and Jersey barriers. Increasing the life of bridge decks by the use of epoxy-coated reinforcing bars, and thousands of other product innovations make today's highways dramatically different from those of 50 years ago. Nevertheless, much more progress could be made in improving the nation's highways by devoting sufficient attention—both financial and managerial—to needed research.

A STRATEGY FOR SETTING PRIORITIES

The limited research in the highway area is largely directed at developing incremental solutions to current local problems. This is logical in view of the diversity of climate, soils, topographies, local paving materials, and traffic loadings throughout different states and counties. It is also top priority for the limited research funding available. The downward trend in research funding has caused the highway industry to overlook or neglect several of the big problems facing the industry as a whole. Research designed to fill these technological gaps must meet many stringent tests. This study outlines a strategy for screening potential research areas to identify the most promising for a national program. Specifically, this strategy involves answering the nine following questions:

1. *Will the research yield big payoffs if successful?*

Many areas of feasible highway research will potentially deliver payoffs far in excess of the necessary original investments. For example, even if research on better asphalt paving materials yielded only a 1 percent reduction in the cost of pavements, this reduction would save $100 million a year—far in excess of the total of $70 million or so now spent on research for highways. Much greater savings would probably result in view of the frequency of premature pavement failures and the ever greater demands that increased traffic and weights of vehicles make on pavements.

2. *Is the research area currently neglected?*

When measured against potential payoffs, virtually all highway research is neglected. However, some categories are funded much more inadequately than others. Research on asphaltic materials, for example, represents only a minuscule fraction of highway research, even though more than 93 percent of all paved roads and streets are surfaced with paving mixtures or surface treatments containing asphalt.

3. *Will the project deal with important research previously hampered by institutional or organizational barriers?*

Improvements in highway products and processes lag when procurement procedures (specifications and low bids) do not encourage the purchase of better products and processes. The profitability of proprietary products, the emphasis on life-cycle costs within procurement processes, and the pressure to buy local materials and services must be considered in choosing realistic research objectives.

4. *Can the research findings be used?*

Research often fails to change practice because of limited understanding, organizational inertia, inflexible standards, preoccupation with first costs, mistrust of change, or a desire to perpetuate jobs. A research program designed without taking into account such obstacles will fail. Nevertheless, determining what is achievable is probably the most difficult, albeit the most crucial, judgment in the entire research process.

Training requirements, organizational changes, investment in equipment, cash flow requirements, personnel implications, and legal liabilities of new approaches can make or break the acceptance of research findings.

Technical research personnel are not necessarily in a position to make these judgments, and, similarly, administrators and political leaders may not be fully aware of the technological options that might be developed. Both viewpoints are needed to identify promising research topics.

5. *Does the research require a large-scale effort?*

Most of the $70 to $75 million now spent on highway research is parceled out in problem-specific contracts of $30,000 to $300,000. Such small-scale efforts can be effective in addressing clear, well-defined problems. However, highway research funds are so broadly distributed that no single organization can attack the major problems that plague the industry.

Pavement performance, in particular, requires long-term research because of the long design life of pavements. The careful evaluation of paving materials and techniques under long-term field conditions could substantially reduce the life-cycle costs of maintenance and construction. Increasing fundamental knowledge of how pavements perform under diverse circumstances and using this knowledge to improve those pavements will require a substantial commitment of time, funds, and research direction.

6. *Does the research require an integrated or national approach?*

Existing highway research procedures are likely to overlook processes such as highway construction that include a sequence of distinctly autonomous steps, each managed by a different organization or unit. Because more than one organization is involved at each stage, none is able to evaluate and control the other stages. A prime example is the construction of an asphaltic pavement, which involves many major steps from mining crude oil to constructing the pavement and opening the road to traffic. The various links in the construction chain are managed by oil companies, refineries, batching plants, aggregate producers, construction companies, and federal, state, and local highway departments. Each depends on the work of the others, but none is able to control the others. However, research on improved binding materials could lead to products and specifications that stimulate more efficient use of resources by all of the organizations involved.

7. *Does the research respond to new and potential changes in national policy?*

Because of the immense variety in local materials, building conditions, and topographic features, the strong problem-solving research capability of state agencies is essential. At the same time this decentralized research structure can lead to duplication, particularly if shifts in national policy create new operational issues simultaneously in all states and counties (e.g. the 55-mph national speed limit or increases in truck size and weight limits). The most efficient and timely response to such changes is to create a coordinated research effort that can immediately address the operational implications of the policy change in all of the states.

8. *Does the research use or respond to other technological changes?*

Technological changes in highway vehicles, communications, materials, and other sciences bring new opportunities and new challenges to all states and counties. If research to tap this potential is too fragmented, it may be incremental and duplicative. Also, not all organizations have the resources or skills to monitor properly new developments in technology. Even more stable technologies, such as asphalt, are subject to far-reaching changes when shifts in petroleum distribution and refining processes occur. Various new technologies, such as miniaturized electronics generated in the space program, may have many more highway applications than are currently being explored.

9. *Will the research affect safety or the environment significantly?*

In addition to major cost savings, research also can help to save some of the 46,000 lives lost each year on the roads and to prevent the suffering of many of the more than 3 million persons injured. For example, research to prevent deterioration of bridge decks could reduce the hazard now posed by potholes and pavement irregularities on bridges and other places where there are no obstruction-free maneuvering zones.

A STRATEGIC RESEARCH PROGRAM

On the basis of the selection strategy discussed in the foregoing sections, six priority areas have emerged where it is believed that a concerted research effort can produce major innovations that will increase the productivity and safety of the nation's highway system. A program focused on these research areas could substantially alleviate the biggest, most pervasive problems now faced by the highway industry. Such a research program could be supported if states would allocate one-quarter of 1 percent of their federal-aid highway funds. The six components of this program are sketched below and organizational and financial implications are addressed in the closing section.

Asphalt

Asphalt use dominates the nation's highway industry. Highway agencies spend $10 billion a year on asphalt pavements—10 times as much as the nation spends on AMTRAK and 6 times as much as is spent on the entire intercity bus industry. Despite the huge sums it spends on asphalt, the highway industry has done very little research to improve this basic material or control its quality. As a result, the highway industry still suffers from premature, costly, and embarrassing pavement failures. Variations in asphalt cements caused by post-embargo shifts in sources of crude oil and new refining processes may have added to this problem. Pavement failures are also caused by substandard construction, faulty mixing, poor quality aggregates, inadequate pavement design, and other factors.

Stable, predictable, clearly specified asphalt cements could greatly reduce pavement failures. Even poorly constructed pavements could last longer if asphalt performance were better understood and if the specifications for this material were developed to compensate for possible failings at other steps of the paving process. Developing improved asphaltic products and specifications will require a closely coordinated research program to

1. Define properties of different asphalts,
2. Improve testing and measuring systems,
3. Determine relationships between asphalt cement and pavement performance,
4. Develop improved asphalt binders, and
5. Validate performance in the field.

The highway industry's use of asphalt is huge and growing. Research on this key product could result in substantial cost savings. But even very modest gains—such as a 1 percent saving in the cost of asphalt paving—would save the industry $100 million per year and more than pay for the research effort in less than 1 year. The five research tasks listed above would cost about $10 million per year for 5 years.

Long-Term Pavement Performance

The nation will spend about $400 billion replacing and rehabilitating pavements before the end of the century. Not only will the Interstate and primary systems need repair but also state, county, and local highways and city streets will require massive investments in pavement. Despite these immense expenditures, no comprehensive research on long-term pavement performance has been conducted since the AASHO Road Test—a large-scale field test completed in 1960. This was an accelerated test done under one set of climate and soil conditions. Fundamental questions concerning climatic effects, maintenance practices, long-term load effects, materials variations, and construction practices remain unanswered.

Answers cannot be found without intensive study of pavements under a large number of actual field conditions over many years. Such a large-scale research program (roughly $10 million per year) over such a long period (approximately 20 years) cannot be undertaken by any existing organization. It requires an unprecedented, long-term commitment that is largely incompatible with the short-run terms of public office and intense budgetary pressures. Nevertheless, the costs represent only about one one-thousandth of what the nation will spend on pavements during the 20 years that the field test would be conducted, and many early results could be obtained in time to reshape future pavement designs and expenditures. In additon, the pavement performance study could help cut the costs that motorists incur from driving on deteriorated highways. It could also help public officials make more informed decisions on axle load limits, cost allocations among various classes of highway vehicles, and restrictions on truck dimensions and configurations.

Maintenance Cost-Effectiveness

Maintaining the nation's 4-million-mile state and local road network currently requires more than one-third of the total highway budget, and the share of highway resources going to maintenance is growing. Despite this spending, continued deterioration of the nation's road systems indicates the need for more efficient and more effective maintenance. Methods, equipment, and materials have not changed significantly in recent years, although both the mileage and traffic volume of the highway system have increased significantly. The opportunity for major improvements through maintenance research is substantial: further mechanization, better repair materials, off-site prefabrication, and more efficient staffing and scheduling could all yield substantial savings.

Protection of Concrete Bridge Components

An epidemic of bridge deterioration has developed throughout the United States. Currently more than 132,000 bridges are classified as structurally deficient, and 3,500 more become deficient each year. About one-third of the structurally deficient bridges are so classified because of deck deterioration. Bridge deterioration will continue unless technology is developed to arrest the corrosion process in existing salt-contaminated bridge decks and other reinforced concrete structural members and to protect new and replacement concrete now being constructed from contamination or corrosion.

The procedures that appear to be the most promising for extending the life of bridge concrete are as follows:

1. Prevent deterioration of chloride-contaminated concrete through electrochemical removal of chlorides, impregnation of the concrete and upper steel, or cathodic protection; and
2. Prevent deterioration of new and uncontaminated concrete by using newly developed coatings for the reinforcing steel and external or internal sealants for the concrete surface.

In addition to the research on the protection of concrete from chlorides, research on alternatives to the use of chlorides for snow and ice control is proposed in another of the six program areas.

Cement and Concrete in Highway Pavements and Structures

The highway industry consumes more than $400 million of portland cement annually; this is about 13 percent of all portland cement made in the United States. Concrete is used for 85,000 miles of roads, thousands of miles of median strips, curbs, and virtually all sidewalks. Also most bridge decks, short-span bridges, and the supporting structures for thousands of bridges are made of concrete. Yet, cement and concrete research is diminishing just at the time when the quality, reliability, and utility of this basic building material are of the most importance.

A major cause for failure in concrete structures is deterioration of the concrete; therefore, research is needed to find ways to increase durability, particularly for structural uses.

Chemical Control of Snow and Ice on Highways

All but 7 of the 50 states can count on snow covering parts of their highway systems every winter. Salt was first used on intercity highways for snow and ice control about 50 years ago; by 1982 salt use had grown to 12 million tons a year. This heavy use of salt for snow and ice control exacts a price in vehicle corrosion, bridge deck and concrete pavement deterioration, and contamination of soils and waters. Two avenues of research could help to reduce the adverse effects of chlorides while maintaining the safe levels of service required on highways during winter storm periods.

First, the storing, handling, applying, and controlling of salt offer many opportunities for improvement, and research should be directed at better chemical management techniques. In addition, research should explore improvements in mechanical and thermal means of snow removal. Second, new chemicals with acceptable melting qualities and without adverse environmental effects should be developed for use in winter maintenance programs, and further assessment should be made of calcium magnesium acetate (CMA) as an alternative to salt.

CONCLUSIONS AND RECOMMENDATIONS

Each of these six proposed research areas represents an outstanding opportunity to fill in the gaps in highway research and make dramatic advances in transportation technology. An assessment of these high priority research areas in terms of the nine strategic criteria previously discussed is given in Table 1.

Together the six research components comprise a program of about $30 million per year for 5 years. This major funding requirement can be met by allocating one-quarter of 1 percent of federal-aid highway funds to research. This procedure would require no new money. Rather, a small fraction of today's program funds would be devoted to reducing tomorrow's program needs by developing better materials and techniques. The data in Table 2 indicate how these funds would be distributed. Cost savings of about $600 million per year could result from implementing new technology developed by this research effort. Although the savings would only be realized after the research results were put into practice, they would continue to accrue long after the research program is completed.

The strategic research plan described in this study is a practical approach to solving real-world problems and is carefully related to the materials and processes used to build and maintain the physical struc-

TABLE 1 Assessment of High-Priority Highway Research Areas

	Asphalt	Long-Term Pavement Performance	Maintenance Cost-Effectiveness	Protection of Concrete Bridge Components	Cement and Concrete in Pavements and Structures	Chemical Control of Snow and Ice
Probability of a big payoff	High	High	High	High	Medium	High
Has research on this topic been neglected in recent years?	Yes	Yes	Yes	No	Yes	Possibly
Degree to which organizational barriers now impede research	High	High	Medium	Low	High	Low
Likelihood that research findings will be usable	High	High	High	High	High	Medium
Scale of effort required for successful project	Large	Large	Small	Large	Medium	Medium
Does the research require greater unity of effort, now splintered?	Yes	Yes	Probably	Probably	Yes	Probably
Do changes in national policy create a common, multistate research need?	Possibly	Yes	Possibly	No	No	Yes
Do major technological changes require research here?	Yes	No	Possibly	Possibly	Possibly	Possibly
Likely magnitude of impact on safety and environment	Medium	High	High	High	Medium	Medium

TABLE 2 A 5-Year Strategic Transportation Research Program

Problem Area	Annual Expenditure ($ Million)	Total Expenditure ($ Million)
Asphalt	10.0	50
Long-term pavement performance[a]	10.0	50
Maintenance cost-effectiveness	4.0	20
Protection of concrete bridge components	2.0	10
Cement and concrete in highway pavements and structures	2.4	12
Chemical control of snow and ice on highways	1.6	8
Totals	30.0	150

[a]Continuation required for an additional 15 years at approximately $10.0 million per year.

tures of the highway system. It is tailored to focus on observed gaps in current research and the organizational structure and resources required to close these gaps. It advocates innovative approaches to down-to-earth problems. The plan can be characterized as follows:

- It is more sharply focused than current highway research efforts.
- It concentrates on a few specific, goal-oriented areas. It would exist for only 5 years (with the exception of the pavement field test, which would necessarily have to be longer).
- It represents a crash effort, a high concentration of time and money and technical expertise on crucially important and achievable targets.
- The staff should be independent of old allegiances thereby ameliorating some organizational barriers.
- It should include involvement by constituent highway operating agencies but insulate research efforts from special interests.
- It should have continuity both of staff and funding throughout its 5-year term and a strong central control.

Because of these special characteristics, no existing organization can simply absorb this strategic program. Various existing organizations could be modified to assume responsibility for this program, including the following:

- An American Association of State Highway and Transportation Officials (AASHTO) task force;
- A special-purpose unit of AASHTO, such as was created to oversee the AASHO Road Test;
- A new component of the National Cooperative Highway Research Program of Highway Research and Development (NCHRP);

- A new special project under the Federally Coordinated Program of Highway Research and Development (FCP);
- A modified Research Associate Program under the auspices of the National Bureau of Standards;
- A university research center or research institute; or
- A major private research organization.

Alternatively, a new organization, such as a special-purpose, chartered, nonprofit research agency, could be considered.

The current infrastructure crisis has reawakened the nation to the economic importance and the physical problems of its highway system. The appropriation by Congress in 1982 of $58 billion in federal aid for highways over 4 years must be matched by a serious, concerted research effort to find better ways to build, maintain, and operate the highway system of the future. Merely increasing support for current research activities will not focus the resources that are crucial to achieving that goal. The strategic research program proposed here is an efficient and productive way to initiate and monitor a concentrated research effort and it is well within the industry's financial ability. With the appropriate funding and institutional commitments, the strategic research program outlined here promises to make a monumental contribution toward improving highway technology.