NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS

December 31, 1993

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NATIONAL RESEARCH COUNCIL

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS

December 31, **1993**

NOTICE TO READERS

On December 31, 1988, a *special edition* of the Summary of Progress was published compiling information on all projects initiated under the NCHRP from its inception in 1962 through 1988. Subsequent editions update the Summary of Progress series, including *only* those projects that were active, or for which some type of activity remained, after January 1, 1989. To obtain a copy of the *Summary of Progress Through 1988—Special Edition*, refer to the final page of this document for ordering information

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL **1993**

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. More predominantly, however, the need for more efficient, economical, and safer highway transportation and the importance of meshing with other modes and other societal concerns leads to national problems of increasing complexity. A coordinated program of high-quality cooperative research provides a highly effective approach to such problems.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. AASHTO's program is supported on a continuing basis by funds from participating member states of the Association and receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer AASHTO's research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; and it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

Research programs are developed annually by AASHTO on the basis of research needs identified by chief administrators of the highway and transportation departments, by committees of AASHTO, and by the Federal Highway Administrator. The programs are then referred for administration through the Transportation Research Board, and research projects addressing the specific needs are defined by the Board on the basis of the AASHTO problem statements. The projects are advertised widely for proposals, and qualified agencies are selected on the basis of research plans offering the greatest probabilities of success. The research is carried out under contract, and administration and surveillance are responsibilities of a Board-appointed staff.

The needs for highway research are many, and the National Cooperative Highway Research Program is an efficient mechanism for providing timely solutions to problems of mutual concern to many responsible groups. The Program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS

DECEMBER 31, 1993

INTRODUCTION

The National Cooperative Highway Research Program (NCHRP) was established in 1962 to provide a continuing program of highway research. It is sponsored by member departments of the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA), U.S. Department of Transportation, and is carried out under a three-way agreement among these agencies and the National Academy of Sciences. AASHTO annually proposes specific research problems for inclusion in the NCHRP fiscal year activities. At least two-thirds of the member departments must approve the research problems and agree to their financial support before they can be brought into the Program. Following balloting by the member departments, the approved problems are referred to the Academy, where they are reviewed to determine their acceptability to the Academy for administration by the Transportation Research Board. Each State annually contracts with the Academy to commit a portion of its Federal-aid state planning and research (SPR) funds. These funds presently make available a cooperative pool of about $15.0 million for NCHRP each year.

Each research project in the program is assigned to a panel made up of persons knowledgeable in the particular problem area. The panel analyzes the problem, outlines the particular project and its objectives, and then prepares a research project statement by which proposals are solicited from qualified research agencies. The panels review the proposals, recommend contract awards, and provide counsel to the NCHRP staff responsible for surveillance of work under the research contracts. Finally, they review final reports for acceptability and for accomplishment of the approved research plan. There are presently more than 950 members on these panels coming from 50 States, the District of Columbia, Puerto Rico, Canada, and Australia.

A professional staff is assigned to NCHRP by the Board. Projects engineers with training and experience in the many research areas encompassed by the Program are responsible for administrative and technical surveillance of the contracts. If necessary, frequent meetings involving the staff, panel, and agency personnel are held to review project progress and provide guidance for ongoing work.

The research findings are published in either of two regular NCHRP report series or as a *Research Results Digest.* Each state highway administrator receives a copy immediately on publication, and as many as 6,000 copies are issued through the Transportation Research Board's Publication's Office.

Twice each year, detailed progress reports are submitted by the NCHRP to the sponsors to provide them with current information on the specifics of technical progress of the projects, as well as the specifics of administrative matters relating to Program operation. These reports are supplemented by publication of an annual summary of progress that is made available at the end of each year to both the sponsors and the public at large.

HOW NCHRP PROGRAMS ARE FORMULATED

NCHRP programs are initiated on an annual basis, and there are many steps between initiation and the time that the final reports are published. Each fiscal year's program must start with the *identification of critical problems* by: state highway and transportation departments, AASHTO Committees, and the Federal Highway Administration.

The many problems (usually for more than 150) received from these sources each year are first screened to determine:

- If the proposed problem represents an immediate research need and is of interest to many states.
- If it can be handled effectively under a cooperative program.
- If similar efforts are already under way, or if satisfactory answers are already available. In these respects, a search is made of the relevant literature stored in the Board's automated Highway Research Information Service.
- The probability of success.

The technical merits of the problems that survive this initial screening (usually about 50 percent) are then evaluated in depth by the AASHTO Standing Committee on Research. Final priorities are determined each year at a meeting to formulate research programs for the NCHRP.

After the program is approved, by AASHTO, it is referred to TRB for execution.

PROGRAMS RECEIVED TO DATE

Through most of NCHRP's history, each year's program generally has consisted of from 10 to 15 new problems, each with funding usually ranging between $200,000 and $400,000 and a like number of continuations of projects funded in earlier years. Measured against the large number of research needs, as evidenced by the list that has ranged as high as 253 problems submitted for evaluation in a single year, the funds made available to the NCHRP each year have been far too limited. For about 15 years, annual funding for the NCHRP remained nearly constant at just below $5 million, while, during this period, the purchasing power of the research dollar was severely reduced by inflation. This decline was reversed with enactment of the Surface Transportation Assistance Act of 1982, which resulted in an approximately 50 percent funding increase for NCHRP. The federal-aid highway legislation enacted in 1987 had the effect of reducing NCHRP funding by 18 percent to a level of about $6.8 million. In February 1988, AASHTO approved a new formula for NCHRP contributions (5.5% of Federal-Aid Highway Planning and Research apportionments) to restore NCHRP funding to approximately $8.3 million starting in fiscal year 1989. The Intermodal Surface Transportation Efficiency Act of 1991 resulted in a funding level of approximately $15.0 million for NCHRP starting in fiscal year 1992.

In 1993, AASHTO referred the FY '94 program of research problems to the TRB for execution. From all programs through FY '94, 613 research contracts have resulted (Table 2), totaling some $121 million. The subject matter of the projects ranges across the full spectrum of concern within the highway industry and evidences the sponsor's immediate interest in acquiring answers at an early date to the many acute problems facing administrators and engineers. The FY '95 program will be formulated in March 1994 by the Standing Committee on Research. Proposals will be solicited starting in 1994. AASHTO's initial steps toward development of the FY '96 research program will be taken early in 1994.

FINANCING THE PROGRAM

Each year, each State contracts with the National Academy of Sciences to support the Program. The agreement commits the State to 5½ percent of its 2 percent federal-aid state planning and research (SPR) funds. From these contributions a cooperative pool of about $15.0 million is presently made available each year for NCHRP's administrative and contract research operations. Funds are scheduled to become available such that research can begin near the end of each year; for example, projects in the FY '94 program were scheduled to begin in December 1993.

HOW THE NCHRP IS ORGANIZED TO ADMINISTER RESEARCH PROGRAMS

All problems are assigned to specific problem areas within each of the eight broad research fields shown in Figure 1 and are given related NCHRP project numbers.

Each project is assigned to a panel consisting of outstand-

NCHRP RESEARCH FIELDS AND AREAS

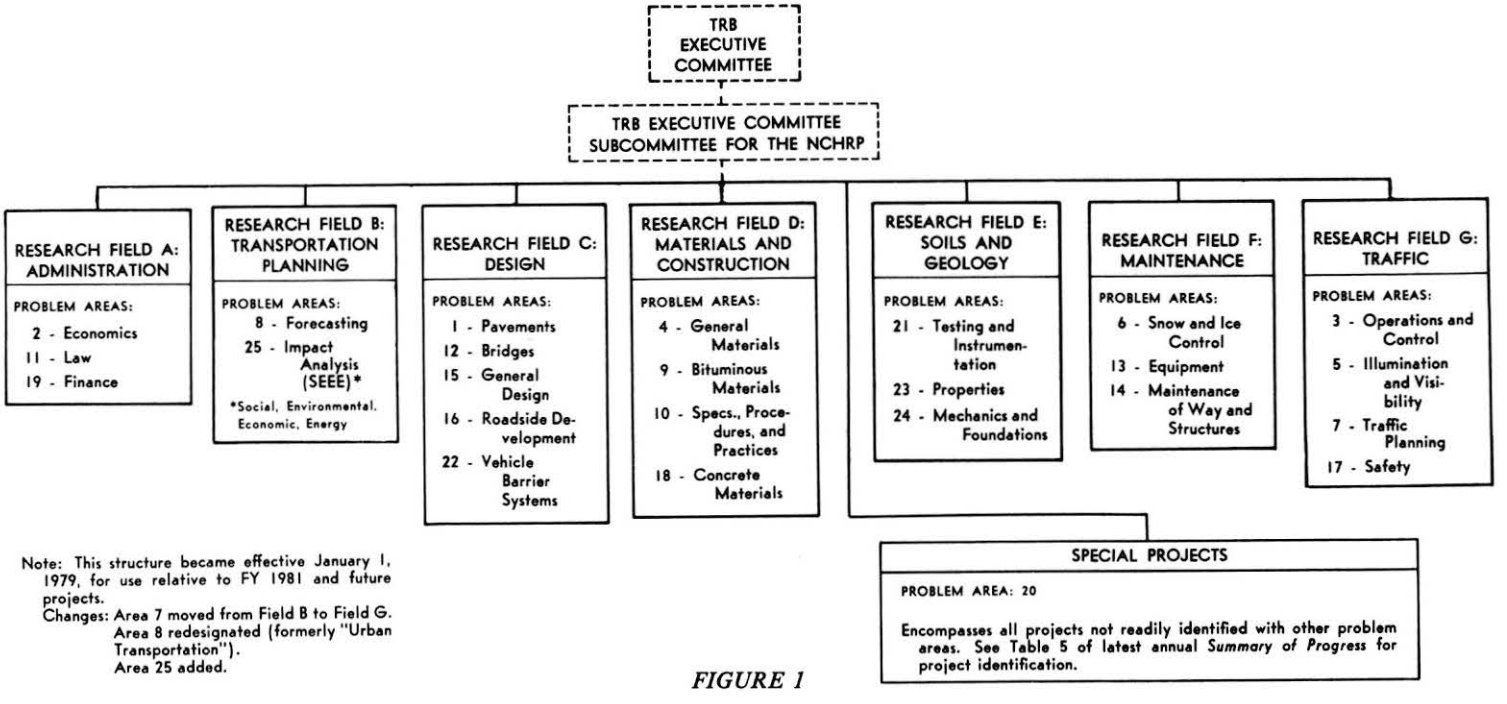

FIGURE 1

TABLE 1

DISTRIBUTION OF PROJECT PANEL AND COMMITTEE MEMBERSHIP WITH RESPECT TO AFFILIATION

AFFILIATION	NO. OF MEMBERS	POSITIONS INVOLVED
State highway and transportation departments	423	513
Federal Highway Administration*	65	84
Special transportation and other governmental agencies	105	110
Educational institutions	143	165
Research institutes	4	7
Industry, consultants, and trade associations	186	213
Professional societies and service organizations	12	11
All	938	1103

* Does not include liaison representatives

ing individuals very knowledgeable in the project area who are looked to for technical guidance and counsel throughout the research and reporting phases. A broad search is made for these individuals, and the Board usually receives about four to five times as many nominees as can be used in the available panel positions. The panels are in existence for the life of their projects. Members do not act as consultants or advisors to project investigators; they may not submit proposals for research. All members serve without compensation, and their total yearly contribution to the Program adds up to thousands of man-days. The panel members are drawn from all walks of professional life, and, as shown in Table 1, heavy dependence is placed on the states for providing members. The perspective of state people in defining the research needed to solve operational problems is most important if projects that are both practical and feasible within the limits of available funds are to be structured.

The duties and responsibilities of project panels include:

- Defining the scope of problems assigned by AASHTO and drafting project statements requesting proposals for studies.
- Evaluating proposals and making recommendations regarding selection of research agencies.
- Monitoring research progress.
- Providing guidance regarding technical aspects of the research.
- Reviewing and evaluating project reports as to the accomplishment of objectives and suitability for publication.
- Making recommendations as to whether or not studies should be continued.

HOW THE PROJECTS ARE PLACED UNDER CONTRACT

It is important to note that **the NCHRP is not in the business of awarding grants for basic research.** Rather, the Program calls for contract research with specific objectives that, if achieved, will result in solutions that are practical and readily usable. As the NCHRP gets each year's program under way, the project panels meet to write research project statements based on the research problems referred by AASHTO.

These statements are then sent automatically to a mailing list of some 4,200 research agencies ranging from individuals to large corporations. Anyone may be added to this list by request addressed to the Director, Cooperative Research Programs at TRB. Because NCHRP operates on a fixed-schedule, proposals must be submitted according to fixed deadlines.

Contracts have been let to agencies headquartered in more than 25 States, the District of Columbia, and one foreign country. The types of agencies selected to conduct NCHRP research are listed in Table 2. The opportunity to propose is open to anyone possessing extensive, demonstrated capability and experience in the problem area. Because the projects call for practical remedies to pressing operational problems, it is expected that only the highest level of agency capability will be applied in meeting the commitments of the proposal—capability cannot be developed at project expense. Consonant with the goal of providing practical, readily usable solutions to pressing problems, time and experience have led to the development of fairly stringent specifications for proposals and agency attributes that are acceptable to the mission-oriented nature of the NCHRP. Proposals must comply with the format in the current brochure, *Information and Instructions for Preparing Proposals.*

TABLE 2

AGENCY DISTRIBUTION OF FY '63 THROUGH FY '94 PROJECTS

TYPE OF AGENCY	CONTRACTS NO.*	CONTRACTS %
Educational institutions	216	35
Research institutes	91	15
Industry, consultants, and trade associations	285	46
Professional societies and service organizations	22	4
State highway and transportation departments	4	< 1
Special transportation and other governmental agencies	3	< 1
All	621	100

* Totals do not include the individual topics and tasks for Projects 20-5, 20-6, and 20-7.

The staff and panel members evaluate all proposals in a uniform manner, with primary consideration given to:

- The understanding of the problem and the merit of the research plan and approach.
- The experiment design and the promise of fulfilling the objectives of the project statement.
- The qualifications of the principal investigator and other members of the research team.
- The adequacy of the facilities.

The proposed budget is not one of the primary factors because the funds available for reseach are announced in the project statement. The budget does not enter the evaluation process leading to agency selection, except when specific items are reviewed to better determine manpower allocations and distribution of resources. When the proposed cost exceeds the funds stated to be available, the proposal is rejected on receipt.

A panel meeting is held to select an agency for each project, and a review is made of all known aspects of performance of the proposers on other research projects under NCHRP or elsewhere. The successful proposals are retained by the panel members for use in monitoring the research. Proposals are considered to be privileged, and the information in them is not released outside the TRB unless explicit approval is obtained from the agency. Policy also holds that panel deliberations and meeting notes are privileged.

Following the selection meetings, a list of recommended research agencies is transmitted to AASHTO and the Federal Highway Administration for their review and approval. Contracts between the Academy and the research agencies are executed, and research is begun. **Again, it should be emphasized that the NCHRP is a program of contract research—it does not operate on a grant basis.** Further, proposals can be received only in response to advertised project statements, as the funds available each year to the Program are earmarked in their entirety for research problems specified by the sponsor—AASHTO.

From the standpoint of AASHTO's interests, needs, and capital investments, it is important to understand that a contract is not signed with the selected agency until the staff and project panel are satisfied that the proposed scope of work provides the best probability for success in meeting AASHTO's needs. In the period between agency selection and contract execution, a concerted effort is made to resolve questions and clarify matters of technical substance emanating from the selection process. This action usually results in an addendum to the research plan in the agency's approved proposal; therefore, both the proposal and the addendum are incorporated in the contract as the binding scope of work. Furthermore, soon after contract execution, the agency is required to submit a Working Plan that is intended to be an amplified version of the research plan. It is against this document that progress of the project is monitored by the staff and project panel.

The policy of the NCHRP is to provide a debriefing to unsuccessful proposers to indicate the technical areas in which their proposals were judged weak and deficient and how the weaknesses or deficiencies were factors in their not having been selected.

The projects included in the 32 fiscal year programs conducted to date are listed in Table 3.

The Academy's research contract is either:

- Cost-Reimbursement
- Cost-Reimbursement Plus Fixed Fee
- Fixed Price

The Academy decides, in agreement with the agency, which type of contract will be used in each case.

KEEPING TRACK OF RESEARCH IN PROGRESS

Once research starts, administrative and technical surveillance of its progress is performed by NCHRP staff, presently standing at 20—11 professional, 9 support. In-depth surveillance by contract managers with wide-ranging expertise contributes much to the probability of project success and can be one of the most significant of the several elements influencing how well objectives are met. It is recognized, however, that a delicate balance must be maintained in the practical exercise of surveillance. It must be penetrating enough to be effective, yet it must not be so complex or burdensome as to distract the researchers from their primary efforts or add unreasonably to the agency's cost of doing business.

In addition to reviewing monthly progress schedules and quarterly progress reports, the projects engineers maintain frequent telephone contacts and regularly visit the research agencies throughout the contract periods. They talk with each principal investigator about the project's status to learn if the research is being pursued in line with the approved research plan, and they provide guidance in all technical and administrative matters. They provide liaison in whatever manner is required to keep their project panels abreast of progress and to acquire panel guidance and counsel in technical matters, particularly as regards the relationships between research objectives and the needs of the practicing engineer. Because the agency's proposal is incorporated in its entirety in the contract, the agency's approved budget is among the items subject to the terms of the agreement. The principal investigator has flexibility in managing the budget up to the point of not materially departing from the approved research plan or exceeding the contract's maximum allowable cost. Major changes to account for promising new leads or unproductive lines of study must be approved in advance by the staff and project panel and are authorized through a contract amendment. Agency invoices are checked monthly by staff for deviations from the approved budget. Based on all surveillance activities, staff prepares its own progress reports, which are sent to the sponsors to provide a current awareness of ongoing work. Finally, the staff and panels evaluate the

completed research to determine the degree of technical compliance with the contract so that recommendations for contract close-out can be made.

A point heavily stressed with the research agencies at the time of the first surveillance visit is that they must orient their thinking toward presentation of their research results in a form that is directly usable by practicing engineers. Further, to enable an easy determination of the usefulness of the results to practice, each final report includes a "Summary of Findings" and a chapter on "Interpretation, Appraisal, and Application of Results." The detailed research techniques and analyses of interest primarily to researchers are offered in appendixes. Such specification of the style and organization of reports guides the researcher in presenting results so that maximum use by the sponsors may be obtained.

NCHRP publications consist of:

- Project reports in the regular NCHRP Report series.
- Reports in the NCHRP Synthesis of Highway Practice series.
- Annual summary of progress through December 31.
- NCHRP Research Results Digests.
- NCHRP Legal Research Digests.
- Semiannual progress reports.

The semiannual progress reports are issued only to the various program participants. The other publications are distributed more widely through the NCHRP and through the Board's selective distribution process; the print order for reports in the formal NCHRP series ranges from 3,500 to 7,000 copies. In addition to AASHTO and the Chief Administrative Officers, copies automatically go to:

- Individual TRB members who have selected publications in the particular subject area of the report.
- About 100 libraries.
- Transportation Research Board representatives in the state highway and transportation departments.
- Educational institutions.
- Liaison representatives.
- Appropriate panels and committees.

News releases announcing the publication of NCHRP reports are sent to appropriate trade publications and other news media. For each report, the NCHRP staff writes a foreword that identifies the fields of specialty of those individuals having most interest in the results. It also suggests how the results fit into present knowledge and practice. Furthermore, the Board's Technical Activities Staff follows the progress of the work and is therefore able to discuss the potential application of research results during their periodic visits to State highway and transportation departments. All published reports are offered for sale through the Board's Publications Office and are also entered in the National Technical Information Service (NTIS). All unpublished reports are placed on microfiche for ready availability to interested parties.

SYSTEMATIC PLANNING FOR GETTING RESEARCH RESULTS FROM NCHRP PROJECTS INTO PRACTICE

Promoting Useful Results

Previous reference has been made to the fact that many activities take place between initiation of research programs and execution of research contracts. Many additional ones take place before formal publication of the final reports is realized. At milestones in the process network reflecting all activities, NCHRP concentrates on the opportunities to increase the probability that useful results will find their way into practice more quickly. Beyond the sponsor's initial contribution of setting the goals for a program of applied research dedicated to solving pressing operational problems, the NCHRP tries to further increase the probability by:

- Establishing the agency and personnel qualifications that are mandatory if the goals are to be achieved. Emphasis is placed on the importance of a record of successful past performance in endeavors similar to those to be undertaken. Further, it is also stipulated that proposals are not acceptable if they do not contain specific statements as to how the anticipated results can be used to improve practice.
- Making use of panel members, who not only are experts in the particular problem area but who also have a complete understanding of the needs of the practitioners, to define the research problem and its objectives in the form of a precise project statement on which fully responsive research proposals can be based. Experts drawn from the highway and transportation departments play a major role in this task.
- Exercising extreme care in the process of selecting research agencies to ensure not only that the proposed research plan is the best possible in addressing the specifics of the objectives but that it also culminates in the best promise for providing the practitioner with a product that is both usable and readily implementable.
- Establishing—on the basis of staff and project panel review of and suggested modifications to the research plan_a clear meeting of the minds as to what specifically is expected from the project and the researchers in order to meet the needs of the practitioner.
- Acquiring an amplified research plan that is intended to detail comprehensively the approved research plan and to include a specific schedule of events for the major tasks. This document is used by the staff in the day-to-day surveillance of the project's progress and by the project panel as required.
- Carrying out project surveillance sufficient to keeping the research in line with the approved research plan, constantly keeping the researchers aware of the needs of the practitioner, and insuring that all project developments through final reporting center around these needs.

• Requiring research reports in a format that is designed specifically to first meet the needs of the busy administrator and the practitioner. Different treatment is given to the material that would be of interest to other researchers.

NCHRP Reporting of Research Results

In an applied research program such as the NCHRP, the sponsor rightfully expects not only results that are accurate but also findings that can be readily put into practice. This means that the final research reports must be presented in language understandable to both administrators and engineers and in such format as to permit easy assimilation. Research reports are sometimes so clouded by obscure language and format that the reader must spend precious time and effort in translating them into concise and readily usable working documents. Research agencies for the NCHRP are required to report their results in a form that succinctly summarizes the findings for the busy administrator and likewise informs the practitioner of the application of the findings. The detailed research techniques and analyses in which a researcher would be interested are presented in appendixes and do not have to be labored through to extract the findings. The Program specifies style and organization of all reports to guide the researcher in his writing so that maximum use by the sponsors may be obtained.

IMPLEMENTING RESEARCH RESULTS

Over the years there have been opportunities for the Program staff and various AASHTO committees to work together to structure the research findings into the best possible form for immediate use by the practitioner. Such joint efforts are highly desirable and represent the ultimate in the steps that the Program can take to weight the odds in favor of implementation of the findings.

AASHTO has provided the NCHRP with frequent opportunities for staff and project researchers to go before the various committees of the Association to present their findings and recommendations directly to the user community.

EXAMPLES OF UTILIZATION OF NCHRP RESEARCH RESULTS

Beyond the uses of NCHRP research results cited in Table 4, there undoubtedly are many other uses that are unknown to the Program. NCHRP reports have been abstracted by numerous foreign countries, including Russia, with subsequent utilization being reported here. In the interest of all potential users, the Program will be grateful for any information on actual application of results and associated cost savings. This will be reported in the hope that widespread interest will develop in the States and that, consequently, research results will find their way more quickly into policies, practices, procedures, specifications, and standards of the highway and transportation departments.

PERSONNEL

In January 1993, FRANK R. MCCULLAGH joined the NCHRP replacing D. W. "Bill" Dearasaugh who took Frank's position in Division A of the Transportation Research Board.

Frank, who holds a B.S. in Civil Engineering from the Newark College of Engineering (New Jersey Institute of Technology), was the Engineer of Design with TRB's Technical Activities Division. He was responsible for organizing the design portion of TRB's Annual Meeting; coordinating specialty conferences (Third Bridge Engineering Conference, for example); and providing correlation services to the states, Federal Highway Administration, and other interested organizations. Previously, as Director of the Arizona Transportation Research Center, Frank managed a broad program of research. In addition, he has worked for the New York State Department of Transportation Bureau of Engineering Research and Development, where he was responsible for research in the pavement area.

Frank has authored more than 20 technical and research reports and has made numerous presentations at transportation-related conferences and workshops. He is a member of the American Society of Civil Engineers, the American Society for Testing of Materials, the Association of Asphalt Paving Technologists, and the International Society of Asphalt Pavements.

STEPHEN E. BLAKE has joined the Cooperative Research Programs staff as a Senior Program Officer and will be monitoring NCHRP projects in the areas of planning, environment, and freight transportation.

Steve, who holds a B.S. in Political Science from North Carolina A&T State University in Greensboro, N.C., was with SEB Associates prior to returning to the Transportation Research Board. As principal researcher in the firm, he conducted planning, environmental, and educational studies for various clients. Prior to SEB Associates, Steve was Director of Research and Special Projects at the National Association of Regional Councils, where he conducted studies not only in transportation but also in the social, economic, and policy fields as well. Steve's earlier experience with TRB was as the Environmental Specialist for the Technical Activities Division, where he was instrumental in establishing many of the committees in the environmental and energy areas.

Steve is the author of numerous papers and research reports and is very active in promoting careers in the field of transportation to university students.

SUMMARY

The National Cooperative Highway Research Program is a unique contract research effort designed to respond quickly and efficiently to the needs of State highway and transportation departments through the solution of the pressing trans-

portation problems. Although the Transportation Research Board administers the Program, the research content is solely the prerogative of the American Association of State Highway and Transportation Officials and its member departments. The Program is one of applied (rather than basic) research, and every possible effort is made to help administrators and engineers put the findings to early use. Program policy ensures maximum exposure of the research while in progress in the hope that research results will, in fact, more quickly find their way into practice in the form of policies, procedures, specifications, and standards of State highway and transportation departments.

TABLE 3
SUMMARY OF STATUS THROUGH DECEMBER 31, 1993, FOR FY '63 THROUGH FY '94 PROJECTS

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA ONE: DESIGN—PAVEMENTS		
1-1(1)	Development of Procedures for Comparing the AASHO Road Test Findings with Performance of (1) Existing Pavements and (2) Newly Constructed Experimental Pavements	HRB	42,800*
1-1(2)	Guidelines for Extending the Findings of the AASHO Road Test—Implementation Phase	HRB	11,356*
1-2	Comparison of Different Methods for Evaluating Pavement Conditions	Purdue U	29,957*
1-3(1)	Factors Influencing Pavement Performance—Regional	Purdue U	45,982*
1-3(2)	Factors Influencing Pavement Performance—Local	Northwestern U	19,850*
1-3(3)	Factors Influencing Pavement Performance	U of California	19,800*
1-4(1)	Extension of Road Test Performance Concepts	Georgia Tech	10,000*
1-4(1)A	Extension of Road Test Performance Concepts	Duke U	19,924*
1-4(2)	Extension of Road Test Performance Concepts	Purdue U	12,243*
1-5	Detecting Variations in Load-Carrying Capacity of Flexible Pavements	Cornell Aero Lab	49,011*
1-5(2)	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements	Texas A & M	49,428*
1-6	Standard Measurements for Satellite Program—Measurement Team	Texas A & M	61,353*
1-7	Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces	Penn State U	24,815*
1-8	Factors Involved in the Design of Asphalt Pavement Surfaces	Materials R & D	23,255*
1-9	Evaluation of Studded Tires	Cornell Aero Lab	24,998*
1-10	Translating AASHO Road Test Findings—Basic Properties of Pavement Components	Materials R & D	99,803* 103,291*
1-10A	Systems Approach to Pavement Design—Implementation Phase	Texas A & M	100,000*
1-10B	Development of Pavement Structural Subsystems	Woodward-Clyde	447,941*
1-11	Evaluation of AASHO Interim Guides for Design of Pavement Structures	Materials R & D	63,720* 20,205*
1-12	Determination of Pavement Friction Coefficients Required for Driving Tasks	Franklin Inst	309,244*
1-12A	Wet-Weather Skidding Accident Reduction at Intersections	Ohio DOT	199,955*
1-12(2)	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques	Penn State U	319,000*
1-12(3)	Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces	Materials R & D	261,955*
1-13	Effects of Studded Tires on Highway Safety	Calspan Corp	208,898*
1-13(2)	Effects of Studded Tires on Highway Safety—Non-Winter Driving Conditions	U of Michigan	39,450*
1-14	Influence of Combined Highway Grade and Horizontal Alignment on Skidding	U of Michigan	69,968*
1-15	Design of Continuously Reinforced Concrete Pavements for Highways	U of Texas	151,870*
1-16	Evaluation of Winter-Driving Traction Aids	Penn State U	304,400*
1-17	Guidelines for Recycling Pavement Materials	Texas A&M	199,470*
1-18	Calibration and Correlation of Response-Type Road Roughness Measuring Systems	U of Michigan	250,000*
1-19	Development of a System for Nationwide Evaluation of PCC Pavements	U of Illinois	225,000*
1-20	Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance	Texas A & M	200,000*
1-21	Repair of Joint-Related Distress in Portland Cement Concrete Pavements	U of Illinois	300,000*
1-22	Shoulder Geometrics and Use Guidelines	Hugh Downs/RK&K	100,000*
1-23	Pavement Roughness and Rideability	KETRON, Inc.	249,990*
1-23(2)	Pavement Roughness and Rideability—Field Evaluation	JMJ Research	199,983*
1-24	Revision of AASHTO Interim Guide for Design of Pavement Structures	McCullough/Finn	—
1-25	Effects of Heavy Vehicle Characteristics on Pavement Response and Performance	TRB	100,000*
1-25(1)	Effects of Heavy Vehicle Characteristics on Pavement Response and Performance—Phase II	U of Michigan	400,000*
1-26	Calibrated Mechanistic Structural Analysis Procedures for Pavements	U of Illinois	499,942
1-27	Video Image Processing for Evaluating Pavement Surface Distress	Triple Vision	350,000*
1-28	Laboratory Determination of Resilient Modulus for Flexible Pavement Design	Georgia Tech	443,433
1-29	Improved Surface Drainage of Pavements	Penn State U	400,000
1-30	Support Under Portland Cement Concrete Pavements	U of Illinois	150,000
1-31	Smoothness Specifications for Pavements	—	400,000
1-32	Systems for Design of Highway Pavements	—	500,000
	AREA TWO: ADMINISTRATION—ECONOMICS		
2-1	Criteria for Highway Benefit Analysis	U of Washington	101,948*
2-2	Guidelines for the Determination of Community Consequences	U of Washington	48,873*
2-3	Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements	Cornell Aero Lab	155,972*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
3/1/63	2/29/64	Completed—Published as NCHRP Reports 2, 2A	1-1(1)
3/1/64	8/31/65	Contract terminated—No report	1-1(2)
2/15/63	2/28/65	Completed—Init. ph. publ. as NCHRP Report 7; final report not publ.; for avail., see Summary of Progress Through 1988	1-2
2/15/63	9/30/67	Completed—Published as NCHRP Report 132	1-3(1)
9/1/63	9/30/64	Completed—Published as NCHRP Report 22	1-3(2)
4/1/64	10/31/65	Completed—Published as NCHRP Report 35	1-3(3)
10/1/63	9/30/64	Completed—Published as NCHRP Report 10	1-4(1)
2/1/65	9/30/66	Completed—Published as NCHRP Report 97	1-4(1)A
2/1/64	1/31/66	Completed—Published as NCHRP Report 30	1-4(2)
1/15/64	7/15/65	Completed—Published as NCHRP Report 21	1-5
9/1/66	6/30/68	Completed—Published as NCHRP Report 76	1-5(2)
3/31/64	1/31/67	Completed—Published as NCHRP Report 59	1-6
6/15/65	12/15/66	Completed—Published as NCHRP Report 37	1-7
1/1/65	2/28/66	Completed—Published as NCHRP Report 39	1-8
10/1/66	6/30/67	Completed—Published as NCHRP Report 61	1-9
9/12/66	3/11/68	Completed—Report included in NCHRP Reports 139, 140	1-10
12/1/68	12/31/70	Completed—Published as NCHRP Reports 139, 140	1-10
3/1/72	12/31/73	Completed—Published as NCHRP Report 160	1-10A
2/1/74	7/31/86	Completed—Published as NCHRP Report 291	1-10B
10/23/67	6/30/70	Completed—Published as NCHRP Report 128	1-11
8/1/70	4/30/71	Completed—Published by AASHTO	1-11
8/25/69	6/8/73	Completed—Published as NCHRP Report 154	1-12
7/1/75	7/1/78	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	1-12A
9/16/70	5/15/73	Completed—Published as NCHRP Report 151	1-12(2)
11/1/71	9/30/75	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	1-12(3)
4/19/71	8/20/74	Completed—Published as NCHRP Report 183	1-13
2/15/72	5/31/73	Completed—Published as NCHRP Report 176	1-13(2)
10/15/72	1/14/74	Completed—Published as NCHRP Report 184	1-14
8/1/72	8/31/75	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	1-15
6/3/74	10/31/81	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	1-16
11/1/76	9/30/79	Completed—Published as NCHRP Report 224	1-17
10/1/77	9/30/80	Completed—Published as NCHRP Report 228	1-18
1/23/78	3/15/85	Completed—Published in NCHRP Report 277	1-19
5/1/79	7/16/84	Completed—Published as NCHRP Reports 268 and 269	1-20
5/15/80	6/28/85	Completed—Published as NCHRP Report 281	1-21
9/8/81	4/7/83	Completed—Published as NCHRP Report 254	1-22
1/4/82	11/30/84	Completed—Published as NCRP Report 275	1-23
1/6/86	12/31/87	Completed—Published as NCHRP Report 308	1-23(2)
—	—	Conducted under Project 20-7, Task 24	1-24
6/12/86	11/30/87	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	1-25
9/1/88	12/31/91	Completed—Published as NCHRP Report 353	1-25(1)
2/6/87	12/31/92	Completed—Report not publ.; for avail., see latest Summary of Progress	1-26
3/1/89	8/31/91	Completed—Report not publ.; for avail., see latest Summary of Progress	1-27
4/15/90	12/1/94	Research in progress	1-28
1/4/93	7/3/95	Research in progress	1-29
1/1/93	6/30/94	Research in progress	1-30
27 months		Contract pending	1-31
33 months		Contract pending	1-32
6/1/63	11/30/67	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	2-1
7/1/63	8/31/64	Completed—Published as NCHRP Report 18	2-2
6/1/63	8/31/66	Completed—Published as NCHRP Report 47	2-3

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWO (*Continued*)		
2-4	The Value of Highway Travel Time, Comfort, Convenience, and Uniform Driving Speed	Texas A & M	77,100*
2-5	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Catholic U	49,998* 51,265*
2-5A	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Paul J. Claffey	35,000* 30,665*
2-6	Warranted Levels of Improvement for Local Rural Roads	Stanford U	40,000*
2-7	Road User Costs in Urban Areas	Catholic U	99,376*
2-8	Estimation and Evalution of Diverted and Generated (Induced) Traffic	Northwestern U	40,000*
2-9	Effect of Highway Landscape Development on Nearby Property	Franklin Inst	149,103*
2-10	Future Needs for Oversize-Overweight Permit Operation on State Highways	Jorgensen & Assoc	99,655*
2-11	Summary and Evaluation of Economic Consequences of Highway Improvements	HRB	110,000*
2-12	Highway User Economic Analysis	Stanford Res Inst	90,074* 9,995*
2-13	Multilane Design Alternatives for Improving Suburban Highways	Midwest Res Inst	100,000*
2-14	Public/Private Partnerships for Financing Highway Improvements	Kimley-Horn & Assoc	175,000*
2-15	Identifying, Measuring, and Evaluating the Benefits of Safety Roadside Rest Areas	KLD Associates	236,560*
2-16	Relationships Between Vehicle Configurations and Highway Design	TRB	912,000*
2-17(1)	Methodologies for Evaluating the Effects of Transportation Policies on the Economy	Hickling Corp	99,145*
2-17(2)	Workshop on Research Needs in Transportation and Economic Development	Greenhorne & O'Mara	52,000*
2-17(3)	Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance	Johns Hopkins U	250,000
2-17(4)	Measuring the Relationship Between Freight Transportation Services and Industry Productivity	Hickling Corp	250,000
2-17(5)	Impact of Urban Congestion on Business	Cambridge Syst Inc	170,000
2-17(6)	Tourism Travel Contributions to Economic Development	Greenhorne & O'Mara	299,448
2-18	Research Strategies for Improving Highway User Cost-Estimating Methodologies	Hickling Corp	200,000
	AREA THREE: TRAFFIC—OPERATIONS AND CONTROL		
3-1	Development of Criteria for Evaluating Traffic Operations	Cornell Aero Lab	78,965* 79,913*
3-2	Surveillance Methods and Ways and Means of Communicating with Drivers	Cornell Aero Lab	246,756*
3-3	Sensing and Communication Between Vehicles	Ohio State U	163,190*
3-4	Means of Locating Disabled or Stopped Vehicles and Methods of Communication with a Central Location	Airborne Instr	78,517* 49,474*
3-5	Improved Criteria for Designing and Timing Traffic Signal Systems	Planning Research	123,030* 48,155* 93,717*
3-6	Effect of Regulatory Devices on Intersectional Capacity and Operation	De Leuw, Cather	153,175*
3-7	Establishment of Standards for Highway Noise Levels	Bolt, Beranek	144,920* 69,930* 49,927* 307,486*
3-8	Factors Influencing Safety at Highway-Rail Grade Crossings	Voorhees & Assoc	17,171* 74,250*
3-9	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control	Jorgensen & Assoc	23,760*
3-10	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations	Cornell Aero Lab	41,520*
3-11	Optimizing Street Operations Through Traffic Regulations and Control	Peat, Marwick et al	258,331*
3-12	Development of Information Requirements and Transmission Techniques for Highway Users	Airborne Instr	198,655* 100,500* 99,821*
3-13	Guidelines for Medial and Marginal Access Control of Major Roadways	Texas A & M	149,293*
3-14	Optimizing Flow on Existing Street Networks	Edwards & Kelcey	990,000*
3-15	Weaving Area Operations Study	Poly Inst of NY	300,000*

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
6/1/63	8/31/66	Completed—Published as NCHRP Report 33	2-4
6/1/63	8/31/64	Completed—Published as NCHRP Report 13	2-5
6/1/65	12/31/66	Completed—Report included in NCHRP Report 111	
7/1/67	12/31/68	Completed—Report included in NCHRP Report 111	2-5A
8/11/69	8/10/70	Completed—Report included in NCHRP Report 111	
6/1/63	9/30/66	Completed—Published as NCHRP Report 63	2-6
2/1/64	5/31/66	Completed—Report included in NCHRP Report 111	2-7
5/1/64	8/31/66	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	2-8
11/8/65	1/31/68	Completed—Published as NCHRP Report 75	2-9
11/1/66	4/30/68	Completed—Published as NCHRP Report 80	2-10
1/1/67	7/31/70	Completed—Published as NCHRP Report 122	2-11
4/1/74	10/31/75	Completed—Report not published	2-12
10/11/76	5/31/77	Completed—Report published by AASHTO	
7/18/83	3/31/85	Completed—Published as NCHRP Report 282	2-13
1/1/86	1/31/90	Completed—Phase I report publ. as NCHRP Report 307; Phase II report published as Research Results Digest 179	2-14
1/13/86	4/30/89	Completed—Published as NCHRP Report 324	2-15
3/2/87	6/30/90	Completed—Published as TRB Special Report 227	2-16
9/1/89	1/31/91	Completed—Published as NCHRP Report 342	2-17(1)
9/1/89	7/31/90	Completed—Report not publ.; for avail., see latest Summary of Progress	2-17(2)
11/1/91	12/31/93	Report in review stage	2-17(3)
10/14/91	3/31/94	Research in progress	2-17(4)
9/15/91	3/15/93	Completed—Publication decision pending	2-17(5)
2/1/93	1/31/95	Research in progress	2-17(6)
1/2/91	12/31/93	Report in editorial and review process	2-18
2/15/63	2/29/64	Completed—Report included in Phase II report	3-1
7/2/64	2/28/66	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	
2/15/63	4/30/66	Completed—Published as NCHRP Reports 9, 28, 29	3-2
2/15/63	11/30/65	Completed—Published as NCHRP Report 51	3-3
3/1/63	3/31/65	Completed—Published as NCHRP Report 6	3-4
7/1/65	12/15/66	Completed—Published as NCHRP Report 40	
3/1/63	12/31/65	Completed—Published as NCHRP Reports 3, 32	3-5
7/1/66	7/31/67	Completed—Published as NCHRP Report 73	
8/1/68	12/31/69	Completed—Published as NCHRP Report 124	
4/1/63	8/15/66	Completed—Published as NCHRP Reports 11, 41	3-6
2/1/64	4/30/67	Completed—Published as NCHRP Report 78	3-7
10/14/68	1/15/70	Completed—Published as NCHRP Report 117	
4/1/71	6/30/72	Completed—Published as NCHRP Report 144	
9/1/72	11/30/74	Completed—Published as NCHRP Reports 173, 174	
12/1/63	12/31/64	Completed—Report included in NCHRP Report 50	3-8
4/1/65	1/6/67	Completed—Total project published as NCHRP Report 50	
10/15/66	1/14/68	Completed—Published as NCHRP Report 84	3-9
1/1/66	3/10/67	Completed—Published as NCHRP Report 68	3-10
9/1/66	9/30/68	Completed—Published as NCHRP Report 110	3-11
10/1/66	12/31/67	Completed—Report included in NCHRP Report 123	3-12
4/1/68	12/1/69	Completed—Report included in NCHRP Report 123	
3/29/71	12/11/72	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	
9/1/67	11/30/69	Completed—Published as NCHRP Report 93	3-13
10/1/67	1/10/70	Completed—Published as NCHRP Report 113	3-14
10/1/69	12/31/73	Completed—Published as NCHRP Report 159	3-15

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA THREE (*Continued*)		
3-16	Freeway Lane Drops	System Dev Corp	99,789*
			76,815*
3-17	Improving Traffic Operations and Safety at Exit Gore Areas	Penn State U	79,983*
3-18(1)	Improved Control Logic for Use with Computer-Controlled Traffic	Stanford Res Inst	323,998*
			57,662*
3-18(2)	Traffic Control in Oversaturated Street Networks	Poly Inst of NY	200,000*
3-18(3)	Cost-Effectiveness Methodology for Evaluation of Signalized Street Network Surveillance and Control Systems	JHK & Assoc	123,267*
3-18(4)	Methodology for Performance Evaluation of Signalized Network Control Strategies	Computran	148,705*
3-19	Grade Effects on Traffic Flow Stability and Capacity	Midwest Res Inst	220,443*
3-20	Traffic Signal Warrants	KLD Associates	120,000*
			81,935*
3-20A	Peak-Hour Traffic Signal Warrants	JHK & Assoc	150,000*
3-21	Motorist Response to Highway Guide Signing	BioTechnology	272,071*
3-21(2)	Effectiveness of Changeable-Message Displays in Advance of High-Speed Freeway Lane Closures	BioTechnology	170,993*
3-22	Guidelines for Design and Operation of Ramp Control Systems	Stanford Res Inst	199,030*
3-22A	Guidelines for Design and Operation of Ramp Control Systems	Texas A & M	249,538*
3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations	KLD Associates	308,779*
3-24	Determine the Luminous Requirements for Retroreflective Highway Signing	U of Michigan	100,000*
3-25	Cost and Safety Effectiveness of Highway Design Elements	Jorgensen & Assoc	260,576*
3-26	Investigation of Selected Noise Barrier Acoustical Parameters	Penn State U	224,494*
3-27	Guidelines for Selecting Traffic Signal Control at Individual Intersections	Voorhees & Assoc	150,000*
3-28	Development of an Improved Highway Capacity Manual	JHK & Assoc	161,000*
3-28A	Two-Lane, Two-Way Rural Highway Capacity	Texas A & M	157,492*
3-28B	New Highway Capacity Manual	Poly Inst of NY	283,440*
3-28C	Effects of Quality of Traffic Signal Progression on Delay	Texas A & M	164,546*
3-28(2)	Urban Signalized Intersection Capacity	JHK & Assoc	331,000*
3-29	Traffic Signal Display Complexity	Systems Tech Inc	196,284*
3-30	Intersection Channelization	Jack E. Leisch Assoc	130,000*
3-31	Guidelines for Evaluating Alternatives for Replacing a Grade-Separated Rail/Highway Crossing	Ernst & Whinney	200,000*
3-32	Temporary Pavement Markings for Work Zones	Texas A & M	164,990*
3-33	Capacity and Level-of-Service Procedures for Multilane Rural and Suburban Highways	JHK & Assoc	475,132*
3-34	The Feasibility of a National Heavy-Vehicle Monitoring System	Arthur D. Little	499,791*
3-35	Speed-Change Lanes	JHK & Assoc	250,000*
3-36	Development of a Low-Cost Bridge Weigh-In-Motion System	Bridge Weighing Sys	400,000*
3-37	Capacity and Level of Service at Ramp-Freeway Junctions	Polytechnic U	400,000
3-38(1)	Assessment of Alternative Technologies for Relieving Urban Traffic Congestion	Castle Rock Consult	202,666*
3-38(1)A	A Study to Assess Advanced Vehicle and Highway Technologies	TRB	345,000
3-38(2)	Travel Characteristics of Large-Scale Suburban Activity Centers	JHK & Assoc	300,000*
3-38(3)	Traffic Adaptive Control (Phase I)—Critical Intersection Control Strategies	Farradyne Systems	149,951
	(Phase II)—OPAC Control Strategies		224,878
3-38(4)	Traffic Signal Control for Saturated Conditions	KLD Associates	270,000*
3-38(5)	Effective Utilization of Street Width	Midwest Res Inst	159,941*
3-38(6)	Cost Sharing for Transportation Improvements Near Major Suburban Employment Centers	Indiana U Fdn	125,000
3-38(7)	Access Management Policies and Guidelines for Activity Centers	Metro Transportation	124,789
			99,970
3-39	Evaluation and Calibration Procedures for Weigh-In-Motion Systems	Texas A&M	398,500
3-39(2)	On-Site Evaluation and Calibration Procedures for Weigh-In-Motion Systems	—	250,000
3-40	Single Point Urban Interchange Design and Operations Analysis	Texas A&M	241,037*
3-41	Procedure for Determining Work Zone Speed Limits	Graham-Migletz	200,000
3-41(2)	Effectiveness and Implementability of Procedures for Work Zone Speed Limits	Graham-Migletz	200,000
3-42	Determination of Stopping Sight Distances	Texas A & M	500,000
3-43	Use of Shoulders and Narrow Lanes to Increase Freeway Capacity	JHK & Assoc	300,000
3-44	Improved Traffic Control Device Design and Placement to Aid the Other Driver	Michigan State U	350,000
3-45	Speed-Flow Relationships for Basic Freeway Segments	JHK & Assoc	350,000
3-46	Capacity and Level-of-Service at Unsignalized Intersections	U of Idaho	400,000
3-47	Capacity Analysis of Interchange Ramp Terminals	Texas A&M	400,000
3-48	Capacity Analysis for Actuated Intersections	U of Florida	250,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
11/1/69	4/30/71	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-16
5/1/72	10/31/73	Completed—Published as NCHRP Report 175	3-16
1/1/71	11/30/72	Completed—Published as NCHRP Report 145	3-17
7/15/71	5/15/74	Completed—Report included in Phase II report	3-18(1)
4/15/75	6/30/77	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	
9/1/71	6/30/75	Completed—Published as NCHRP Report 194	3-18(2)
5/1/75	4/15/77	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-18(3)
7/21/77	11/20/80	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-18(4)
9/1/71	8/31/74	Completed—Published as NCHRP Report 185	3-19
9/1/72	4/15/74	Completed—Report included in Phase II report	3-20
11/1/74	12/31/76	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	
6/23/80	7/31/82	Completed—Published as NCHRP Report 249	3-20A
4/1/74	1/31/76	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-21
12/1/79	8/31/81	Completed—Published as NCHRP Report 235	3-21(2)
4/15/74	12/31/75	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-22
2/1/77	3/31/81	Completed—Published as NCHRP Report 232	3-22A
4/8/74	7/28/77	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-23
9/1/74	4/30/77	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-24
7/15/75	4/16/78	Completed—Published as NCHRP Report 197	3-25
12/1/76	2/28/80	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-26
11/15/76	7/31/79	Completed—Published as NCHRP Report 233	3-27
12/15/77	8/15/79	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-28
5/1/80	2/28/83	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-28A
7/1/82	3/31/85	Completed—Published as Highway Capacity Manual (TRB Special Report 209)	3-28B
8/1/86	7/31/88	Completed—Published as NCHRP Report 339	3-28C
10/1/79	8/31/82	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-28(2)
7/1/83	3/31/86	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	3-29
7/1/83	5/15/85	Completed—Published as NCHRP Report 279	3-30
9/4/84	2/28/87	Completed—Published as NCHRP Report 288	3-31
5/1/85	2/28/87	Completed—Report not publ.; for avail., see latest Summary of Progress	3-32
6/1/85	4/30/90	Completed—Report not publ.; for avail., see latest Summary of Progress	3-33
11/1/85	9/30/88	Completed—Published as NCHRP Report 303	3-34
6/1/86	5/31/89	Completed—Report not publ.; for avail., see latest Summary of Progress	3-35
2/16/87	10/31/91	Completed—Report not publ.; agency report avail. for loan	3-36
7/1/90	12/31/93	Completed—Report not publ.; agency report avail. for loan	3-37
7/1/87	6/30/91	Completed—Published as NCHRP Report 340	3-38(1)
7/1/89	3/31/91	Completed—Published as TRB Special Report 232	3-38(1)A
6/1/87	3/31/89	Completed—Published as NCHRP Report 323	3-38(2)
9/1/87	3/15/90	Completed—Report not publ.; agency report available for loan	3-38(3)
12/15/90	3/31/93	Completed—Report not publ.; agency report available for loan	
10/1/87	6/4/92	Completed—Report not publ.; for avail., see latest Summary of Progress	3-38(4)
4/1/88	6/30/90	Completed—Published as NCHRP Report 330	3-38(5)
5/15/88	2/28/91	Completed—Report not publ.; for avail., see latest Summary of Progress	3-38(6)
5/15/89	9/30/93	Completed—Report publ. as NCHRP Report 348	3-38(7)
3/30/92	9/30/93	Completed—Publication decision pending	
3/1/88	12/31/93	Report in review stage	3-39
21 months		Contract pending	3-39(2)
5/1/89	11/30/91	Completed—Report published as NCHRP Report 345	3-40
11/15/89	5/31/93	Report in editorial & publication process	3-41
		Contract pending	3-41(2)
5/1/91	5/1/94	Research in progress	3-42
1/15/91	4/15/94	Completed—Report in review stage	3-43
4/15/92	10/15/94	Research in progress	3-44
11/1/92	4/30/95	Research in progress	3-45
1/1/93	6/30/95	Research in progress	3-46
1/15/94	7/15/96	Research in progress	3-47
12/1/93	12/30/95	Research in progress	3-48

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA THREE (*Continued*)		
3-49	Capacity and Operational Effects of Midblock Left-Turn Lanes	U of Nebraska	300,000
3-50	Driver Information Overload	Comsis Corp	300,000
3-51	Communication Mediums for Signal, IVHS, and Freeway Surveillance Systems	Kimley-Horn & Assoc	350,000
	AREA FOUR: MATERIALS AND CONSTRUCTION—GENERAL MATERIALS		
4-1	Development of Appropropriate Methods for Evaluating the Effectiveness of Stabilizing Agents	U of Illinois	114,991*
4-2	A Study of Degrading Aggregates in Bases and Subbases with Production of Excessive Amounts of and/or Harmful Types of Fines	Purdue U	63,990*
4-3(1)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	VPI	20,000* 23,337*
4-3(2)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	Penn State U	56,457* 49,756*
4-4	Synthetic Aggregates for Highway Uses	Battelle Mem Inst	14,790*
4-5	A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture	Michigan Tech U	64,105*
4-6	Protective Coatings for Highway Structural Steel	Steel Str Paint	25,000*
4-7	Fatigue Strength of High-Yield Reinforcing Bars	PCA	100,000* 50,000*
4-8	Research Needs Relating to Performance of Aggregates in Highway Construction	VPI	55,254*
4-8(2)	Density Standards for Field Compaction of Granular Bases and Subbases	Clemson U	95,248*
4-8(3)	Predicting Moisture-Induced Damage to Asphaltic Concrete	U of Idaho	190,177* 70,860*
4-8(4)	Predicting Moisture-Induced Damage to Asphaltic Concrete—10-year Field Evaluation	U of Idaho	24,402*
4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	Utah DOT	93,494*
4-9(1)	Preformed Elastomeric Pavement Joint Sealing Systems—Field Evaluation Phase	Utah DOT	144,837*
4-10	Promising Replacements for Conventional Aggregates for Highway Use	U of Illinois	50,000*
4-10A	Waste Materials as Potential Replacements for Highway Aggregates	Valley Forge Lab	53,663*
4-11	Buried Plastic Pipe for Drainage of Transportation Facilities	Simpson Gumpertz	200,000*
4-12	Upgrading of Poor or Marginal Aggregates for PCC and Bituminous Pavements	Penn State U	149,941*
4-13	Temporary Pavement Marking Systems	Sw Research Inst	49,500*
4-13A	Temporary Pavement Marking Paint Systems	Georgia Tech	69,971*
4-14	Coating Systems for Painting Old and New Structural Steel	Georgia Tech	199,302*
4-15	Corrosion Protection of Prestressing Systems in Concrete Bridges	Wiss, Janney, Elstner	249,973*
4-16	Cost and Service Life of Pavement Markings	Penn State U	340,327*
4-17	Environmental Monitoring and Evaluation of Calcium Magnesium Acetate (CMA)	U of Washington	199,943*
4-18	Design and Evaluation of Large Stone Mixtures	Texas A & M	300,000
4-19	Aggregate Tests Related to Asphalt Concrete Performance in Pavements	—	500,000
	AREA FIVE: TRAFFIC—ILLUMINATION AND VISIBILITY		
5-2(1)	Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents	Yale University	124,319* 21,530*
5-2(2)	Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort	Ohio State U	81,187*
5-2(3)	Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort	Inst for Research	37,460*
5-3	Visual Information Needed by the Driver at Night	Ohio State U	100,940*
5-4	Economic Study of Roadway Lighting	Franklin Inst	19,412*
5-5	Nighttime Use of Highway Pavement Delineation Materials	Sw Research Inst	50,000* 100,000*
5-5A	Development of Optimum Specifications for Glass Beads in Pavement Markings	Penn State U	99,350*
5-5B	Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing Is Prevalent	Texas A & M	200,000*
5-6	Highway Fog	Cornell Aero Lab	99,955*
5-6A	Highway Fog	Sperry Rand	93,540*
5-7	Roadway Delineation Systems	Penn State U	469,526*
5-8	Warrants for Highway Lighting	Texas A & M	198,875*
5-9	Partial Lighting of Interchanges	KETRON, Inc.	199,999*
5-10	A Mobile System for Measuring Retroreflectance of Traffic Signs	EKTRON Appl Image	480,795*
5-11	Implementation Strategies for Sign Retroreflectivity Standards	Bellomo-McGee	203,544*

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
12/1/93	2/28/96	Research in progress	3-49
1/1/94	3/31/97	Research in progress	3-50
11/15/93	12/15/95	Research in progress	3-51
6/1/63	10/31/66	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	4-1
2/15/63	11/30/66	Completed—Published as NCHRP Report 98	4-2
3/1/63	9/30/64	Completed—Published as NCHRP Report 12	4-3(1)
7/1/65	3/31/67	Completed—Published as NCHRP Report 65	4-3(1)
3/25/63	1/31/65	Completed—Published as HRB Special Report 80 and NCHRP Report 15	4-3(2)
7/1/65	8/3/67	Completed—Published as NCHRP Report 66	4-3(2)
3/1/63	4/15/64	Completed—Published as NCHRP Report 8	4-4
2/15/63	8/31/65	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	4-5
3/1/65	11/30/66	Completed—Published as NCHRP Reports 74, 74A, 74B	4-6
10/1/67	2/28/70	Completed—Report included in NCHRP Report 164	4-7
2/1/71	8/31/73	Completed—Report included in NCHRP Report 164	
1/1/68	4/30/69	Completed—Published as NCHRP Report 100	4-8
4/1/71	6/30/73	Completed—Published as NCHRP Report 172	4-8(2)
9/1/71	3/31/74	Completed—Published as NCHRP Report 192	4-8(3)
8/1/75	1/31/82	Completed—Published as NCHRP Report 246	4-8(3)
6/1/85	1/31/87	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	4-8(4)
10/1/68	6/30/71	Completed—Report included in Phase II report	4-9
10/1/72	12/31/79	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	4-9(1)
10/15/69	3/31/71	Completed—Published as NCHRP Report 135	4-10
9/1/72	11/30/73	Completed—Published as NCHRP Report 166	4-10A
9/16/74	1/26/79	Completed—Published as NCHRP Report 225	4-11
12/1/76	5/31/79	Completed—Published as NCHRP Report 207	4-12
11/1/76	2/28/78	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	4-13
4/1/78	9/30/79	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	4-13A
1/1/78	12/31/81	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	4-14
7/1/82	11/30/85	Completed—Published as NCHRP Report 313	4-15
10/1/84	8/30/90	Completed—Report not publ.; for avail., see latest Summary of Progress	4-16
1/7/85	10/31/87	Completed—Published as NCHRP Report 305	4-17
6/1/92	11/30/94	Research in progress	4-18
36 months		Contract pending	4-19
2/15/63	5/31/66	Completed—Report included in NCHRP Report 60	5-2(1)
2/1/67	7/31/67	Completed—Report included in NCHRP Report 60	
2/15/63	8/31/65	Completed—Report included in NCHRP Report 60	5-2(2)
2/20/63	2/28/66	Completed—Report included in NCHRP Report 60	5-2(3)
9/1/64	3/31/67	Completed—Published as NCHRP Report 99	5-3
7/20/64	8/31/65	Completed—Published as NCHRP Report 20	5-4
3/1/65	12/31/66	Completed—Published as NCHRP Report 45	5-5
7/15/67	9/15/69	Completed—Published as NCHRP Report 85	
5/1/71	6/30/73	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	5-5A
9/1/71	12/31/74	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	5-5B
10/2/67	4/30/69	Completed—Published as NCHRP Report 95	5-6
9/1/70	5/31/73	Completed—Published as NCHRP Report 171	5-6A
10/1/68	6/30/71	Completed—Published as NCHRP Report 130	5-7
3/16/70	2/15/73	Completed—Published as NCHRP Report 152	5-8
12/1/80	1/31/83	Completed—Published as NCHRP Report 256	5-9
9/7/87	12/31/90	Completed—Reports not publ.; for avail., see latest Summary of Progress	5-10
2/15/89	8/31/91	Completed—Published as NCHRP Report 346	5-11

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA FIVE (*Continued*)		
5-12	Requirements for Application of Light Emitting Diodes (LEDs) to Traffic Control Signals	Lighting Sciences	249,973
5-13	Illumination Guidelines for Nighttime Highway Work	U of Florida	173,979
5-14	Advance Warning Arrow Panel Visibility	The Last Resource	275,000
	AREA SIX: MAINTENANCE—SNOW AND ICE CONTROL		
6-1	Development of Economical and Effective Chemical Deicing Agents to Minimize Injury to Highway Structures and Vehicles	IIT Research Inst	40,000*
6-2	Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures	Jorgensen & Assoc	25,000*
6-3	Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents	Battelle Mem Inst	58,557*
6-4	Evaluation and Development of Methods for Reducing Corrosion of Reinforcing Steel	Battelle Mem Inst	39,330*
6-5	Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents	U of Illinois	72,500*
6-6	To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete	Ohio State U	69,393*
6-7	Estimation of Disintegration in Concrete Structures	Geotechnics	8,547*
6-7A	Estimation of Disintegration in Concrete Structures	IIT Research Inst	44,614*
6-8	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures	Tallamy Assoc	25,000*
6-9	Potential Acclerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks	U of Illinois	200,000*
6-10	Develop Improved Snow Removal and Ice Control Techniques at Interchanges	Tallamy Assoc	95,000*
6-11	Economic Evaluation of the Effects of Ice and Frost on Bridge Decks	Midwest Res Inst	50,000* 50,000*
6-12	Improved Visibility for Snow Plowing Operations	—	300,000
	AREA SEVEN: TRAFFIC—TRAFFIC PLANNING		
7-1	The Influence of Land Use on Urban Travel Patterns	Louis E. Keefer	62,674* 66,894*
7-2	Traffic Attraction of Rural Outdoor Recreational Areas	IIT Research Inst	24,652* 24,844*
7-3	Weighing Vehicles in Motion	Franklin Inst	73,391*
7-4	Factors and Trends in Trip Lengths	Voorhees & Assoc	89,250* 61,730*
7-5	Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage	Yale University	99,675*
7-6	Multiple Use of Lands Within Highway Rights-of-Way	Barton-Aschman	24,220*
7-7	Motorists' Needs and Services on Interstate Highways	Airborne Instr	99,267*
7-8	User Cost and Related Consequences of Alternative Levels of Highway Service	Stanford Res Inst	99,070*
7-9	Development of Models for Predicting Weekend Recreational Traffic	Midwest Res Inst	74,983*
7-10	Peak-Period Traffic Congestion	Remak/Rosenbloom	49,624*
7-10(2)	The Institutional Aspects of Implementing Congestion-Reducing Techniques	Remak/Rosenbloom	74,703*
7-11	Low-Cost TSM Projects—Simplified Procedures for Evaluation and Setting Priorities	Multiplications Inc.	199,988*
7-11A	Low-Cost TSM Projects—Simplified Procedures for Evaluation, Phase II	Texas A & M	150,000*
7-12	Microcomputer Evaluation of Highway User Benefits	Texas A & M	200,000
7-13	Quantifying Congestion	Texas A & M	275,000
	AREA EIGHT: TRANSPORTATION PLANNING—FORECASTING		
8-1	Social and Economic Factors Affecting Travel	Vogt, Ivers	94,558*
8-2	Factors Influencing Modal Trip Assignment	IIT Research Inst	298,033*
8-3	Individual Preferences for Various Means of Transportation	U of Penn	63,282*
8-4	Criteria for Evaluating Alternative Transportation Plans	Northwestern U	89,900*
8-4A	Criteria for Evaluating Alternative Transportation Plans	U of Illinois	5,000*
8-5	Transportation Aspects of Land-Use Controls	Victor Gruen	25,967* 99,571*
8-6	Individual Preferences for Alternative Dwelling Types and Environments	U of N Carolina	99,897*
8-7	Evaluation of Data Requirements and Collection Techniques for Transportation Planning	Creighton-Hamburg	190,000*
8-7A	Data Requirements and Transportation Planning Procedures in Small Urban Areas	U of Tennessee	98,005*

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
2/15/92	8/15/94	Research in progress	5-12
2/1/93	10/31/94	Research in progress	5-13
1/2/93	2/28/95	Research in progress	5-14
2/15/63	9/30/64	Completed—Published as NCHRP Report 19	6-1
2/15/63	2/29/64	Completed—Published as NCHRP Report 4	6-2
3/1/63	2/28/65	Completed—Published as NCHRP Report 16	6-3
3/1/63	4/30/65	Completed—Published as NCHRP Report 23	6-4
3/1/63	8/31/65	Completed—Published as NCHRP Report 27	6-5
3/1/63	2/28/66	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	6-6
3/1/63	8/31/64	Contract terminated—no report; research resumed under Project 6-7A	6-7
2/1/65	7/31/66	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	6-7A
2/15/63	2/29/64	Completed—Published as NCHRP Report 1	6-8
1/1/65	6/15/68	Completed—Published as NCHRP Report 101	6-9
9/1/67	9/30/70	Completed—Published as NCHRP Report 127	6-10
9/1/70	11/30/71	Completed—Report included in Phase II report	6-11
9/12/72	9/11/74	Completed—Published as NCHRP Report 182	
36 months		In developmental stage	6-12
2/1/64	1/31/66	Completed—Published as NCHRP Report 24	7-1
4/1/66	9/30/67	Completed—Published as NCHRP Report 62	
2/1/64	3/15/65	Completed—Report included in NCHRP Report 44	7-2
5/1/65	5/31/66	Completed—Total project published as NCHRP Report 44	
2/1/64	8/31/67	Completed—Published as NCHRP Report 71	7-3
2/1/64	10/31/66	Completed—Published as NCHRP Report 48	7-4
10/23/67	1/10/69	Completed—Published as NCHRP Report 89	
2/1/64	11/30/66	Completed—Published as NCHRP Report 58	7-5
2/1/66	2/28/67	Completed—Published as NCHRP Report 53	7-6
1/1/66	12/31/67	Completed—Published as NCHRP Report 64	7-7
9/1/70	4/15/72	Completed—Published as NCHRP Report 133	7-8
9/1/72	5/15/74	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	7-9
4/1/74	3/31/75	Completed—Published as NCHRP Report 169	7-10
4/1/75	11/30/78	Completed—Published as NCHRP Report 205	7-10(2)
4/6/81	11/30/83	Completed—Published as NCHRP Report 263	7-11
3/4/85	8/3/86	Completed—Published as NCHRP Report 283	7-11A
2/1/89	12/31/93	Research in progress (contract extension pending)	7-12
3/1/92	2/28/94	Research in progress	7-13
2/1/64	9/23/66	Completed—Published as NCHRP Report 70	8-1
2/1/64	8/31/66	Completed—Published as NCHRP Report 57	8-2
2/1/64	3/31/65	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	8-3
2/1/65	8/1/67	Completed—Report included in NCHRP Report 96	8-4
10/14/68	1/10/69	Completed—Published as NCHRP Report 96	8-4A
4/1/65	5/31/66	Completed—Published as NCHRP Report 31	8-5
8/7/67	1/15/70	Completed—Published as NCHRP Report 121	
2/14/66	3/13/68	Completed—Published as NCHRP Report 81	8-6
9/13/68	8/28/70	Completed—Published as NCHRP Report 120	8-7
6/1/73	6/14/75	Completed—Published as NCHRP Report 167	8-7A

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA EIGHT (*Continued*)		
8-8(1)	The Impact of Highways upon Environmental Values (Study Design)	M I T	29,654*
8-8(2)	The Impact of Highways upon Environmental Values (Study Design)	Daniel, Mann et al	28,950*
8-8(3)	The Impact of Highways upon Environmental Values	M I T	470,000*
8-9	Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems	Creighton-Hamburg	100,000*
8-10	Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities	Wilbur Smith Assoc	149,907*
8-11	Social, Economic, Environmental Consequences of Not Constructing a Transportation Facility	DACP, Inc	364,363*
8-12	Travel Estimation Procedures for Quick Response to Urban Policy Issues	Metro Wash COG	39,895*
8-12A	Travel Estimation Procedures for Quick Response to Urban Policy Issues	COMSIS Corp	239,331*
8-13	Disaggregate Travel Demand Models	Chas River Assoc	100,000*
8-13(2)	Disaggregate Travel Demand Models	Chas River Assoc	200,000*
8-14	New Approaches to Understanding Travel Behavior	Boston College	144,135*
8-14A	New Approaches to Understanding Travel Behavior: Phase II	Chas River Assoc	221,250*
8-15	State and Regional Transportation Impact Identification and Measurement	Bigelow-Crain	80,000*
8-15A	Economic Impacts of State Transportation Policies and Programs	Reg Sc Res Inst	117,852*
8-16	Guidelines for Public Transportation Levels of Service and Evaluation	U of Tennessee	489,952*
8-17	Freight Data Requirements for Statewide Transportation Systems Planning	R. Creighton Assoc	231,147*
8-18	Techniques for Evaluating Options in Statewide Transportation Planning/Programming	Plng Envr Int/AMV	300,393*
8-19	The Relationship of Changes in Urban Highway Supply to Vehicle-Miles of Travel	Cambridge Syst Inc	199,954*
8-20	Improved Methods for Vehicle Counting and Determining Vehicle-Miles of Travel	Hamburg & Assoc	200,000*
8-21	Guidelines for Use of Vanpools and Carpools as a Transportation System Management Technique	Geo Washington U	265,486*
8-22	Transportation Financing Within the Context of Energy Constraints	System Des Concepts	100,000*
8-23	Fuel Supply Limitations and Passenger Travel	Chas River Assoc	110,000*
8-24	Forecasting the Basic Inputs to Transportation Planning	Hamburg & Assoc	81,000*
8-24A	Forecasting the Basic Inputs to Transportation Planning at the Zonal Level	COMSIS Corp	192,444*
8-25	Intercity Bus Transportation Planning	Peat, Marwick et al	200,000*
8-26	Development of Highway Traffic Data for Project Planning and Design in Urbanized Areas	JHK & Assoc	100,000*
8-27	Cost-Effectiveness of Transportation Services for Handicapped Persons	U of Tennessee	199,543*
8-28	Strategic Planning and Management for Transportation Agencies	Ernst & Young	180,020*
8-29	Travel Estimation Techniques for Urban Planning	Barton-Aschman	300,000
8-30	Characteristics and Changes in Freight Transportation Demand	Cambridge Syst Inc	500,000
8-31	Long-Term Availability of Multimodal Corridor Capacity	The Urban Institute	285,000
8-32	Workshop on Multimodal Transportation Planning Research Needs	TRB	60,000
	AREA NINE: MATERIALS AND CONSTRUCTION—BITUMINOUS MATERIALS		
9-1	Asphalt Durability and Its Relation to Pavement Performance	American Oil	50,000* 50,000*
9-2	Asphalt Durability and Its Relation to Pavement Performance—Adhesion	Montana College	101,903*
9-3	Evaluation of Pavement Joint and Crack Sealing Materials and Practices	Rensselaer	24,996*
9-4	Minimizing Premature Cracking of Asphaltic Concrete Pavements	Materials R & D	99,560*
9-4A	Bayesian Analysis Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress	Woodward-Clyde	204,194*
9-5	Design of Emulsified Asphalt Paving Mixtures	Asphalt Inst	150,172*
9-6A	Development of Asphalt Aggregate Mixture Analysis System: Phase I	ARE Inc	25,000*
9-6B	Development of Asphalt Aggregate Mixture Analysis System: Phase I	Brent Rauhut Eng	25,000*
9-6C	Development of Asphalt Aggregate Mixture Analysis System: Phase I	U of Maryland	24,879*
9-6(1)	Asphalt Aggregate Mixture Analysis System (AAMAS)	Brent Rauhut Eng	660,017*
9-7	Field Procedures and Equipment to Implement SHRP Asphalt Specifications	Brent Rauhut Eng	900,000
9-8	Designing Stone Matrix Asphalt Mixtures	—	500,000
	AREA TEN: MATERIALS AND CONSTRUCTION—SPECIFICATIONS, PROCEDURES, AND PRACTICES		
10-1	Development of Guidelines for Practical and Realistic Construction Specifications	Miller-Warden	25,000*
10-2	Evaluation of Construction Control Procedures	Miller-Warden	59,750*
10-2A	Evaluation of Construction Control Procedures	Materials R & D	70,945*
10-3	Effects of Different Methods of Stockpiling and Handling Aggregates	Miller-Warden	25,000* 30,000*

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
9/16/68	3/14/69	Completed—Study design, not published	8-8(1)
9/9/68	3/7/69	Completed—Study design, not published	8-8(2)
9/15/69	7/31/74	Completed—Published as NCHRP Report 156	8-8(3)
9/1/71	1/31/73	Completed—Published as NCHRP Report 146	8-9
9/1/71	7/31/73	Completed—Published as NCHRP Reports 143 and 155	8-10
9/16/74	11/30/79	Completed—Phase I report not publ.; for avail., see Summary of Progress Through 1988. Phase II report published as NCHRP Reports 216 and 217	8-11
9/3/74	12/31/75	Completed—Results published in 8-12A report	8-12
11/1/75	10/31/78	Completed—Published as NCHRP Reports 186 and 187	8-12A
9/15/74	1/31/76	Completed—Phase I report not publ.; for avail., see Summary of Progress Through 1988	8-13
5/1/76	12/31/80	Completed—Published as NCHRP Report 253	8-13(2)
1/1/75	4/30/77	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	8-14
1/1/78	6/30/82	Completed—Published as NCHRP Report 250	8-14A
9/1/74	5/31/76	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	8-15
10/1/77	3/31/80	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	8-15A
1/1/76	12/31/80	Completed—Published as NCHRP Reports 208, 209, 210, 211, 212	8-16
7/15/75	2/15/77	Completed—Published as NCHRP Reports 177 and 178	8-17
9/1/75	6/30/78	Completed—Published as NCHRP Reports 179 and 199	8-18
12/1/76	11/30/78	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	8-19
1/2/78	7/31/80	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	8-20
3/1/79	6/30/81	Completed—Guidelines published as NCHRP Report 241; research report not publ.; for avail., see Summary of Progress Through 1988	8-21
3/26/79	2/27/81	Completed—Published as NCHRP Report 231	8-22
4/2/79	9/1/80	Completed—Published as NCHRP Report 229	8-23
1/21/80	4/30/82	Completed—Published as NCHRP Report 266	8-24
4/1/87	2/28/90	Completed—Published as NCHRP Report 328	8-24A
4/1/80	1/31/82	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	8-25
5/15/81	12/31/82	Completed—Published as NCHRP Report 255	8-26
9/1/81	4/30/83	Completed—Published as NCHRP Reports 261 and 262	8-27
6/1/87	6/25/90	Completed—Published as NCHRP Report 331	8-28
2/15/91	2/14/93	Completed—Report in review stage	8-29
12/15/92	3/15/95	Research in progress	8-30
1/4/93	1/6/95	Research in progress	8-31
1/10/93	12/31/93	Draft report under review	8-32
2/1/64	7/31/65	Completed—Report included in NCHRP Report 67	9-1
11/1/65	4/30/67	Completed—Total project published as NCHRP Report 67	
1/1/65	10/31/67	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	9-2
6/1/65	6/30/66	Completed—Published as NCHRP Report 38	9-3
11/1/71	6/30/73	Completed—Published as NCHRP Report 195	9-4
9/15/75	11/1/78	Completed—Published as NCHRP Report 213	9-4A
4/1/80	6/30/84	Completed—Published as NCHRP Report 259	9-5
6/2/86	10/2/86	Completed—Report not published	9-6A
6/2/86	10/2/86	Completed—Report not published	9-6B
6/2/86	10/2/86	Completed—Report not published	9-6C
1/5/87	6/4/90	Completed—Published as NCHRP Report 338	9-6(1)
4/1/93	9/30/96	Research in progress	9-7
24 months		Contract pending	9-8
11/15/63	11/14/64	Completed—Published as NCHRP Report 17	10-1
11/4/63	2/1/66	Completed—Published as NCHRP Report 34	10-2
7/15/66	11/14/67	Completed—Published as NCHRP Report 69	10-2A
10/22/63	4/30/64	Completed—Published as NCHRP Report 5	10-3
10/15/64	10/16/65	Completed—Published as NCHRP Report 46	

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TEN (*Continued*)		
10-4	Rapid Test Methods for Field Control of Construction	Clemson U	30,000* 69,320*
10-5	Density and Moisture Content Measurements by Nuclear Methods	Res Triangle Inst	28,801* 59,835*
10-5A	Optimization of Nuclear Density and Moisture Content Measurement Methods	N Carolina State U	51,214*
10-6	Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods	IIT Research Inst	108,821*
10-7	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction	Ohio State U	24,310*
10-8	Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position	Pa Dept of Transp	151,982*
10-9	Criteria for Need of Seal Coats for Bituminous Pavements	U of Minnesota	50,000*
10-10	Acceptance Criteria for Electroslag Weldments in Bridges	US Steel	300,000*
10-11	Development of a Performance Specification for Bridge Deck Joint-Sealing Systems	Howard, Needles et al	29,996*
10-12	Acceptance of Aggregates Used in Bituminous Paving Mixtures	Texas A & M	174,411*
10-13	Ultrasonic Measurement of Weld Flaw Size	The Welding Inst	126,000* 250,000*
10-14	Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques	Georgia Tech	99,850*
10-15	Structural Strength Evaluation of Existing Reinforced Concrete Bridges	Engrg Comp Corp	125,000* 100,000*
10-16	Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline	Byrd, Tallamy et al	150,000*
10-17	Use of Antistripping Additives in Asphaltic Concrete Mixtures	David G. Tunnicliff	497,335* 179,000
10-18	Specifying and Obtaining Entrained Air in Concrete	Const Tech Lab/PCA	73,585*
10-19	Adding Dust Collector Fines to Asphalt Paving Mixtures	Penn State U	49,926*
10-20	Elastomeric Bearings Design, Construction, and Materials	U of Washington	74,715* 150,000*
10-20A	High-Load, Multi-Rotational Bridge Bearings: Design, Materials, and Construction	U of Washington	150,000 265,398
10-21	Performance of Bridge Deck Concrete Subjected to Traffic-Induced Vibrations During Placement	TRB	25,000*
10-22	The Performance of Weathering Steel in Bridges	Sheladia Assoc	74,851* 120,699*
10-23	Removal of Lead-Based Bridge Paints	Midwest Res Inst	81,118*
10-24	Rapid Replacement of PCC Pavement Segments	ARE Inc	240,000
10-25	Measurement of Cement and Water Content of Fresh Concrete	USACE WES	148,303*
10-25A	Instantaneous Determination of Water-Cement Ratio in Fresh Concrete	Wiss, Janney, Elstner	272,431*
10-26	Data Bases for Performance-Related Specifications for Highway Construction	ARE Inc	60,000*
10-26A	Performance-Related Specifications for Hot Mix Asphaltic Concrete	Penn State U	250,000*
10-27	Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing	Texas A & M	449,519*
10-28	A Method to Determine Deteriorated Areas in Portland Cement Concrete Pavements	Gulf Applied Res	199,784
10-29	Anchorage Zone Reinforcement for Post-Tensioned Concrete Girders	U of Texas	489,223*
10-30(1)	Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables	U of Manchester	25,000*
10-30(2)	Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables	Sw Research Inst	25,000*
10-30(3)	Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables	U of Manchester	400,000*
10-31	Acceptance Criteria for Steel Bridge Welds	Matls Res Lab Inc	348,350*
10-32	Durability of In-Place Concrete Containing High-Range Water-Reducing Admixtures	Const Tech Lab/PCA	99,811
10-32A	Durability Testing of High-Strength Concrete Containing High-Range Water-Reducing Admixtures	Utah State U	249,238
10-33	Potential Benefits of Geosynthetics in Flexible Pavement Systems	Georgia Tech Res	100,000*
10-34	Transient Protection, Grounding, and Shielding of Electronic Traffic Control Equipment	Georgia Tech Res	339,988
10-35	Fatigue Behavior of Welded and Mechanical Splices in Reinforcing Steel	Wiss, Janney, Elstner	300,000*
10-36	Evaluation of Weldments Incorporating Backing Materials	Fleet Technology	349,475
10-37	Performance of Epoxy-Coated Reinforcing Steel in Highway Bridges	Kenneth C. Clear	350,000
10-38	Fatigue-Resistant Design of Cantilevered Signal, Sign, and Light Supports	Lehigh U	300,000
10-39	Construction Testing and Inspection Levels	Bergstralh-Shaw et al	140,000
10-40	Plasma Arc Cutting of Bridge Steels	Edison Welding Inst	268,688

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
2/1/64	2/28/65	Completed—Report included in NCHRP Report 103	10-4
5/1/65	2/28/67	Completed—Published as NCHRP Report 103	
1/15/64	1/31/65	Completed—Published as NCHRP Report 14	10-5
4/1/65	10/7/66	Completed—Published as NCHRP Report 43	
2/1/68	1/31/70	Completed—Published as NCHRP Report 125	10-5A
2/1/64	10/31/66	Completed—Published as NCHRP Report 52	10-6
2/1/64	3/31/65	Completed—Published as NCHRP Report 25	10-7
3/2/70	7/31/73	Completed—Published as NCHRP Report 168	10-8
11/1/69	2/28/74	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	10-9
5/1/74	9/30/78	Completed—Published as NCHRP Report 201	10-10
12/1/76	4/30/78	Completed—Published as NCHRP Report 204	10-11
9/1/77	6/30/81	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	10-12
7/1/79	10/31/81	Completed—Published as NCHRP Report 242	10-13
10/1/82	8/31/85	Completed—Report not publ.; for avail., see latest Summary of Progress	
4/2/79	5/1/81	Completed—Published as NCHRP Report 237	10-14
4/1/80	9/30/82	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	10-15
4/1/84	4/30/86	Completed—Published as NCHRP Report 292	10-15
2/16/81	12/1/82	Completed—Published as NCHRP Report 251	10-16
3/1/81	7/1/89	Completed—Phase I report publ. as NCHRP Report 274; Phase II interim report avail. for loan	10-17
9/1/92	6/1/94	Research in Progress	
5/4/81	6/1/83	Completed—Published as NCHRP Report 258	10-18
3/1/81	11/30/82	Completed—Published as NCHRP Report 252	10-19
2/1/81	6/30/82	Completed—Published as NCHRP Report 248	10-20
6/1/83	11/30/86	Completed—Published as NCHRP Report 298	
6/1/86	5/31/89	Completed—Published as NCHRP Report 325	
8/4/89	9/30/93	Report in editorial and publication process	10-20A
2/1/80	9/30/81	Completed—Published as NCHRP Synthesis 86	10-21
4/1/82	2/29/84	Completed—Published as NCHRP Report 272	10-22
7/23/84	8/31/87	Completed—Published as NCHRP Report 314	
7/1/82	6/30/83	Completed—Published as NCHRP Report 265	10-23
3/15/82	3/14/88	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	10-24
10/13/83	9/5/86	Completed—Published as NCHRP Report 284	10-25
6/1/85	2/15/90	Completed—Report not publ.; for avail., see latest Summary of Progress	10-25A
6/15/83	9/14/84	Completed—Report not publ., for avail., see Summary of Progress Through 1988	10-26
1/6/86	9/30/89	Completed—Published as NCHRP Report 332	10-26A
9/17/84	8/31/89	Completed—Published as NCHRP Report 327	10-27
11/1/85	12/31/87	Completed—Published as NCHRP Report 304	10-28
10/1/86	9/30/92	Completed—Report to be published as NCHRP Report 356	10-29
1/6/86	9/29/86	Completed—Report not publ., for avail., see Summary of Progress Through 1988	10-30(1)
1/20/86	10/3/86	Completed—Report not publ., for avail., see Summary of Progress Through 1988	10-30(2)
7/1/87	4/30/91	Completed—Report not publ.; for avail., see latest Summary of Progress	10-30(3)
1/1/86	12/31/89	Completed—Published as NCHRP Report 335	10-31
1/6/86	7/5/87	Completed—Published as NCHRP Report 296	10-32
10/1/87	4/30/93	Report in review stage	10-32A
1/6/86	12/15/88	Completed—Published as NCHRP Report 315	10-33
3/1/86	4/30/92	Completed—Phase I report publ. as NCHRP Report 317; Phase II agency report and video avail. for loan	10-34
11/1/87	4/30/91	Completed—Report in editorial and publication process	10-35
5/2/88	9/30/93	Research in progress (contract extension pending)	10-36
5/1/91	4/30/94	Research in progress	10-37
1/1/93	6/30/95	Research in progress	10-38
1/6/93	12/5/93	Research in progress (contract extension pending)	10-39
1/18/93	4/17/95	Research in progress	10-40

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TEN (*Continued*)		
10-41	Evaluation of Unbonded Portland Cement Concrete Overlays	—	200,000
10-42	Constructibility Review Process for Transportation Facilities	—	250,000
10-43	Movable Bridge Inspection, Evaluation, and Maintenance	—	250,000
	AREA ELEVEN: ADMINISTRATION—LAW		
11-1	Rules of Compensability and Valuation in Highway Land Acquisition	U of Wisconsin	84,840*
11-1(1)	Eliminating Enhancement or Diminution Effects on Right-of-Way Valuation	Real Estate Res	5,000*
11-1(2)	Recognition of Benefits to Remainder Property in Highway Valuation	Montano & Assoc	5,000*
11-1(3)	Taxation Aspects of Right-of-Way Acquisition	U of Tulsa	2,250*
11-1(4)	Compensation in the Nature of Additives to Market Value	U of Oklahoma	2,500*
11-1(5)	Rules of Discovery and Disclosure in Highway Condemnation Proceedings	Long, Mikkelborg	2,500*
11-1(6)	Valuation and Condemnation Problems of Selected Special Purpose Properties	Edward E. Level	7,500*
11-1(7)	Valuation and Compensability of Noise, Pollution, and Other Environmental Factors	U of Oklahoma	2,500*
11-1(8)	Remainder Damages Caused by Drainage, Runoff, Blasting, and Slides	Harrison Lewis	7,500*
11-1(9)	Valuation and Condemnation Problems Involving Trade Fixtures	Edward L. Snitzer	5,000*
11-1(10)	Compensability and Valuation Aspects of Residential Displacement in Highway Programs	Ross, Hardies et al	5,000*
11-1(11)	Valuation Elements of Joint Development Projects, Including Air Rights	Real Estate Res	5,000*
11-2	Theory and Practice in Inverse Condemnation	Reg & Urban Plan	15,000*
11-3	Valuation and Legal Implications of Scenic, Conservation, and Roadside Easements	Sutte, Jr. & Assoc	25,000*
11-3(1)	Public Control of Roadside Advertising Signs for Highway Beautification	Sutte, Jr. & Assoc	20,000*
11-3(2)	Public Control of Junkyards for Highway Beautification	Real Estate Res	13,300*
11-4	Elimination of Wide Divergence in Right-of-Way Valuation	Am Inst Rl Est App	24,959*
11-5	Valuation of Air Space	Daniel, Mann et al	49,800*
11-6	Valuation and Compensability of Noise Pollution	Jack Faucett Assoc	94,744*
	AREA TWELVE: DESIGN—BRIDGES		
12-1	Deformation of Steel Beams Related to Permitted Highway Bridge Overloads	U of Missouri	50,000*
12-2	Distribution of Wheel Loads on Highway Bridges	Iowa State U	79,512*
12-3	Development of Waterproof Roadway Joints for Bridges	Sw Research Inst	149,895*
12-4	Thermal Characteristics of Highway Bridges	Sw Research Inst	102,400*
12-5	Protection of Steel in Prestressed Concrete Bridges	U of Denver	173,255*
12-6	Prediction of Permanent Camber of Bridges	U of Missouri	82,253*
12-7	Effects of Weldments on Fatigue Strength of Steel Beams	Lehigh University	199,023*
12-8	Bridge Rail Service Requirements as a Basis for Design Criteria	Texas A & M	200,000* 28,793* 69,753*
12-9	Elastomeric Bearing Research	Battelle Mem Inst	84,800*
12-10	Analysis and Design of Bridge Bents	PCA	297,900*
12-11	Waterproof Membranes for Protection of Concrete Bridge Decks	Materials R & D	206,025* 96,979*
12-12	Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings	US Steel	310,000*
12-13	Cathodic Protection for Reinforced Concrete Bridge Decks	USS Eng & Consult	174,601*
12-13A	Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks	PCA	74,405*
12-14	Subcritical Crack Growth in Steel Bridge Members	US Steel	99,923*
12-15	Detection and Repair of Fatigue Cracking in Highway Bridges	Lehigh U	100,000*
12-15(2)	Retrofitting Procedures for Fatigue-Damaged Full-Scale Welded Bridge Beams	Lehigh U	150,000*
12-15(3)	Fatigue Behavior of Full-Scale Welded Bridge Attachments	Lehigh U	125,000*
12-15(4)	Steel Bridge Members Under Variable-Amplitude, Long-Life Fatigue Loading	Lehigh U	150,000*
12-15(5)	Fatigue Behavior of Variable-Loaded Bridge Details Near the Fatigue Limit	Lehigh U	399,999*
12-16	Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel	Battelle Columbus	214,912*
12-17	Evaluation of Repair Techniques for Damaged Steel Bridge Members	Battelle Columbus	49,974*
12-17A	Guidelines for Evaluation and Repair of Damaged Steel Bridge Members	Shanafelt/Horn	99,950*
12-18	Development of an Integrated Bridge Design System	Multiplications Inc	224,985*
12-18A	Assessment of an Integrated Bridge Design System	Engrg Comp Corp	15,000*
12-19	Cathodic Protection of Concrete Bridge Structures	Corrosion Eng & Res	250,000*
12-19A	Concrete Sealers for Protection of Bridge Structures	Wiss, Janney, Elstner	99,190*
12-19B	Cathodic Protection of Concrete Bridge Structures	Wiss, Janney, Elstner	138,900*

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
21 months		Contract pending	10-41
27 months		Contract pending	10-42
27 months		Contract pending	10-43
1/1/65	4/30/67	Completed—Published as NCHRP Report 104	11-1
9/2/68	2/28/69	Completed—Published as NCHRP Report 114	11-1(1)
10/1/68	3/31/69	Completed—Published as NCHRP Report 88	11-1(2)
9/16/68	4/30/69	No final report—Project terminated	11-1(3)
12/1/68	5/31/69	Completed—Report not publ.; for avail., See Summary of Progress Through 1988	11-1(4)
9/15/68	4/14/69	Completed—Published as NCHRP Report 87	11-1(5)
9/2/68	11/28/69	Completed—Published as NCHRP Report 92	11-1(6)
10/1/68	3/31/69	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	11-1(7)
10/15/68	1/15/70	Completed—Published as NCHRP Report 134	11-1(8)
3/15/69	12/1/69	Completed—Published as NCHRP Report 94	11-1(9)
3/15/69	9/15/69	Completed—Published as NCHRP Report 107	11-1(10)
2/24/69	8/25/69	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	11-1(11)
2/1/65	6/30/66	Completed—Published as NCHRP Report 72	11-2
11/1/66	12/15/67	Completed—Published as NCHRP Report 56	11-3
10/1/68	12/31/69	Completed—Published as NCHRP Report 119	11-3(1)
9/2/68	2/28/70	Completed—Published as NCHRP Report 112	11-3(2)
7/1/69	2/28/71	Completed—Published as NCHRP Report 126	11-4
10/1/70	5/31/72	Completed—Published as NCHRP Report 142	11-5
4/1/74	7/31/75	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	11-6
2/1/65	6/30/67	Completed—Report included in Project 12-6 report	12-1
6/1/66	12/31/68	Completed—Published as NCHRP Report 83	12-2
12/15/65	3/14/69	Completed—Report available only to sponsors	12-3
12/15/65	3/31/68	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	12-4
9/15/66	11/15/68	Completed—Published as NCHRP Report 90	12-5
2/1/67	4/30/72	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	12-6
10/1/66	1/31/70	Completed—Published as NCHRP Report 102	12-7
7/1/70	12/31/72	Completed—Published as NCHRP Report 147	
3/1/68	2/28/69	Completed—Published as NCHRP Report 86	12-8
1/2/70	6/30/71	Completed—Published as NCHRP Report 149	
9/1/67	1/31/70	Completed—Published as NCHRP Report 109	12-9
1/1/70	12/31/73	Completed—Published as NCHRP Report 163	12-10
8/1/70	3/31/73	Completed—Published as NCHRP Report 165	12-11
7/15/73	9/30/78	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	
10/1/70	10/31/75	Completed—Published as NCHRP Report 188	12-12
10/1/72	7/31/74	Completed—Published as NCHRP Report 180	12-13
8/1/75	5/15/81	Completed—Published as NCHRP Report 234	12-13A
10/1/72	6/30/74	Completed—Published as NCHRP Report 181	12-14
10/1/72	4/30/75	Completed—Published as NCHRP Report 206	12-15
6/1/76	11/30/78	Completed—Published as NCHRP Report 206	12-15(2)
2/1/78	7/31/80	Completed—Published as NCHRP Report 227	12-15(3)
4/1/80	9/30/83	Completed—Published as NCHRP Report 267	12-15(4)
9/1/83	12/31/90	Completed—Interim report publ. as NCHRP Report 286; final rep. publ. as NCHRP Report 354	12-15(5)
9/1/74	11/30/77	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	12-16
11/15/76	4/30/78	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	12-17
10/1/81	5/31/84	Completed—Published as NCHRP Report 271	12-17A
9/6/77	12/31/82	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	12-18
2/1/84	1/3/86	Completed—Report available only to sponsors	12-18A
1/1/78	12/31/80	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	12-19
8/1/79	12/1/81	Completed—Published as NCHRP Report 244	12-19A
11/1/82	4/30/85	Completed—Published as NCHRP Report 278	12-19B

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWELVE (*Continued*)		
12-20	Bridges on Secondary Highways and Local Roads: Rehabilitation and Replacement	U of Virginia	119,923* 49,955*
12-21	Evaluation of Damage and Methods of Repair for Prestressed Concrete Bridge Members	G. O. Shanafelt Shanafelt/Horn	58,520* 129,934*
12-22	Thermal Effects in Concrete Bridge Superstructures	Engrg Comp Corp	100,000*
12-23	Recommended Revisions to the AASHTO *Manual for Maintenance Inspection of Bridges*	A. G. Lichtenstein	233,800*
12-24	Design of Multi-Beam Precast Bridge Superstructures	U of Washington	149,879*
12-25	Fatigue and Fracture Evaluation for Rating Riveted Steel Bridges	Lehigh U	199,957*
12-26	Distribution of Wheel Loads on Highway Bridges	Imbsen & Assoc	300,000* 200,000*
12-26(2)	Distribution of Wheel Loads on Highway Bridges—Analysis Software	Imbsen & Assoc	100,000
12-27	Welded Repair of Cracks in Steel Bridge Members	The Welding Inst	374,575*
12-28(1)	Load Capacity Evaluation of Existing Bridges	Case Western Res U	302,000*
12-28(2)	Bridge Management Systems	ARE Inc	225,000* 270,000*
12-28(2)A	Bridge Management Software	Nat'l Engrg Tech Corp	525,000
12-28(3)	Fatigue Evaluation Procedures for Steel Bridges	Case Western Res U	200,000*
12-28(4)	Methods of Strengthening Existing Highway Bridges	Iowa State U	164,985*
12-28(5)	Standard Methodology for Conducting Condition Surveys of Concrete Bridge Components	New Mexico State U	98,338*
12-28(6)	Distortion-Induced Fatigue Cracking in Steel Bridges	Lehigh U	250,000*
12-28(7)	Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges	Modjeski and Masters	298,644*
12-28(8)	Improving Bridge Load Capacity Estimates by Correlation with Test Data	U of Tennessee	191,024*
12-28(9)	Methods of Flaw Detection in Concrete Bridge Components	—	—
12-28(10)	Guidelines for Determining Redundancy in Steel Bridges	Lehigh U	299,995*
12-28(11)	Development of Site-Specific Load Models for Bridge Rating	Imbsen & Assoc	200,000*
12-28(12)	Inelastic Rating Procedures for Steel Beam and Girder Bridges	U of Minnesota	241,031*
12-28(13)	Nondestructive Load Testing for Bridge Evaluation and Rating	Raths, Raths et al	150,000*
12-28(13)A	Bridge Rating Through Nondestructive Load Testing	A. G. Lichtenstein	227,200
12-29	Design of Simple-Span Precast Prestressed Bridge Girders Made Continuous	Constr Tech Lab/PCA	241,993*
12-30	Fatigue of Cables in Cable-Stayed Bridges	Acer Freeman Fox Ltd	124,975
12-31	Notch Toughness Variability in Bridge Steel Plates	U of Texas	385,000*
12-32	Evaluation of Bridge Deck Protective Strategies	U of Washington	92,515*
12-33	Development of a Comprehensive Bridge Specification and Commentary	Modjeski and Masters	1,390,587
12-33A	Development of a Comprehensive Bridge Specification and Commentary—Timber Structures and Code Calibration	Sensei Engineers	60,000
12-33B	Development of a Comprehensive Bridge Specification and Commentary—Concrete Structures	Imbsen & Assoc	125,500*
12-33C	Development of a Comprehensive Bridge Specification and Commentary—Soil Structure Interaction Systems	D'Appolonnia	83,832*
12-34	Update of AASHTO *Standard Specifications for Highway Bridges:* Division II—Construction	Imbsen & Assoc	200,000*
12-35	Recommended Specifications for the Design of Foundations, Retaining Walls, and Substructures	D'Appolonia	99,588*
12-36	Redundancy in Highway Bridge Superstructures	CUNY	200,000
12-37	Transverse Cracking in Newly Constructed Bridge Decks	Wiss, Janney, Elstner	350,000
12-38	Improved Design Specifications for Horizontally Curved Steel Girder Highway Bridges	Auburn U	300,000
12-39	Design Specifications for Debris Forces on Highway Bridges	U of Louisville	299,977
12-40	Fatigue Criteria for Modular Bridge Expansion Joints	—	335,000
12-41	Rapid Replacement of Bridge Decks	—	500,000
	AREA THIRTEEN: MAINTENANCE—EQUIPMENT		
13-1	Equipment Rental Rates	Ernst & Ernst	22,800*
	AREA FOURTEEN: MAINTENANCE—MAINTENANCE OF WAY AND STRUCTURES		
14-1	Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements	Tallamy Assoc	205,128*
14-2	Tecnhiques for Reducing Roadway Occupancy During Routine Maintenance Activities	Byrd, Tallamy et al	200,000*

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
3/1/78	2/29/80	Completed—Published as NCHRP Report 222	12-20
6/1/80	11/30/81	Completed—Published as NCHRP Report 243	
4/15/79	9/14/80	Completed—Published as NCHRP Report 226	12-21
5/15/82	7/8/85	Completed—Published as NCHRP Report 280	
10/1/81	1/31/84	Completed—Published as NCHRP Report 276	12-22
1/3/89	8/3/92	Completed—Final report distributed to sponsor	12-23
8/1/83	5/31/86	Completed—Published as NCHRP Report 287	12-24
9/1/84	9/30/87	Completed—Published as NCHRP Report 302	12-25
4/15/85	12/15/87	Completed—Report not publ.; for avail., see proj. writeup in latest Summary of Progress	12-26
8/22/88	10/31/90	Published as Research Results Digest 187	
9/28/92	12/31/93	Research in progress	12-26(2)
10/15/84	2/28/89	Completed—Published as NCHRP Report 321	12-27
9/1/85	8/31/89	Completed—Published as NCHRP Report 301	12-28(1)
6/24/85	6/23/87	Completed—Published as NCHRP Report 300	12-28(2)
11/2/87	4/30/90	Completed—No final report	
1/10/92	9/30/94	Research in progress	12-28(2)A
7/1/85	9/30/87	Completed—Published as NCHRP Report 299	12-28(3)
7/1/85	7/31/87	Completed—Published as NCHRP Report 293	12-28(4)
8/1/85	8/31/87	Completed—Published as NCHRP Report 312	12-28(5)
10/1/85	11/30/89	Completed—Published as NCHRP Report 336	12-28(6)
5/5/86	11/30/89	Completed—Published as NCHRP Report 333	12-28(7)
2/1/86	2/19/88	Completed—Published as NCHRP Report 306	12-28(8)
—	—	Combined with Project 10-30(3)	12-28(9)
3/1/86	5/31/89	Completed—Published as NCHRP Report 319	12-28(10)
2/9/87	3/30/90	Completed—Report not publ.; agency report avail. for loan	12-28(11)
9/1/87	5/30/90	Completed—Published as NCHRP Report 352	12-28(12)
10/4/87	9/30/89	Completed—Report not publ.; for avail., see latest Summary of Progress	12-28(13)
12/17/90	11/30/93	Research in progress	12-28(13)A
8/26/85	5/31/88	Completed—Published as NCHRP Report 322	12-29
1/13/86	2/12/89	Completed—Report not publ.; agency report avail. for loan	12-30
9/1/87	9/1/92	Completed—Published as NCHRP Report 355	12-31
4/1/86	5/15/87	Completed—Published as NCHRP Report 297	12-32
7/1/88	10/31/93	Research in progress	12-33
9/19/88	12/31/90	Completed—No report	12-33A
9/16/88	3/31/92	Completed—No report	12-33B
7/24/89	3/31/92	Completed—No report	12-33C
10/19/87	10/18/89	Completed—Report not publ.; for avail., see latest Summary of Progress	12-34
1/4/88	7/3/89	Completed—Report not publ.; for avail., see latest Summary of Progress	12-35
4/8/91	11/16/93	Research in progress	12-36
1/27/92	1/26/95	Research in progress	12-37
1/1/93	3/31/95	Research in progress	12-38
3/1/93	5/31/95	Research in progress	12-39
27 months		Contract pending	12-40
36 months		Contract pending	12-41
2/1/65	1/31/66	Completed—Published as NCHRP Report 26	13-1
3/1/65	3/31/67	Completed—Published as NCHRP Report 42	14-1
10/1/70	3/31/73	Completed—Published as NCHRP Report 161	14-2

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA FOURTEEN (*Continued*)		
14-3	Improved Pavement-Shoulder Joint Design	Georgia Tech	100,838*
14-4	Reconditioning Heavy-Duty Freeways in Urban Areas	Texas A & M	99,665*
14-5	Maintenance Levels-of-Service Guidelines	Woodward-Clyde	204,200*
14-5(2)	Maintenance Levels-of-Service Guidelines	Woodward-Clyde	107,950*
14-6	Evaluating Deferred Maintenance Strategies	ARE Inc	325,000*
14-7	Interactive Microcomputer Network for Innovative Maintenance Operations	Woodward-Clyde	82,819*
14-8	Chip Seal Coats for High-Traffic-Volume Asphalt Concrete Pavements	Intermtn Res Fdn	80,078
14-8A	Chip Seal Coats for High-Traffic-Volume Asphalt Concrete Pavements	Asphalt Inst	159,922
14-9	Workshop on Research Needs in the Management of Highway Maintenance	TRB	42,000*
14-9(1)	Effective Maintenance Budget Strategies	Urban Institute	300,000
14-9(2)	Incorporation of Maintenance Considerations in Highway Design	Daniel, Mann et al	168,122*
14-9(3)	Maintenance Contracting	Bergstralh-Shaw et al	150,000*
14-9(4)	Role of Highway Maintenance in Integrated Management Systems	Cambridge Systematics	225,000
14-9(5)	Impacts of Environmental, Health, and Safety Regulations on Highway Maintenance	Auburn U	150,000
14-9(6)	Professional Development of Maintenance Engineers and Managers	U of Maryland	174,998
14-10	Improvements in Data Acquisition Technology for Maintenance Management Systems	Urban Institute	100,000* 200,000*
14-11	Effective Motivation of Highway Maintenance Personnel	Penn State U	200,000
	AREA FIFTEEN: DESIGN—GENERAL DESIGN		
15-1	Guardrail Design	Cornell Aero Lab	19,723*
15-1(2)	Guardrail Performance and Design	Sw Research Inst	280,000* 100,000*
15-2	Design to Control Erosion in Roadside Drainage Channels	U of Minnesota	97,300*
15-3	Rational Structural Analysis and Design of Pipe Culverts	Northwestern U	49,937*
15-4	Estimating Runoff Rates from Small Rural Watersheds	Travelers Res Cen	299,902*
15-5	Dynamic Characteristics of Heavy Highway Vehicles	Gen Mot Corp	135,000*
15-6	Development of Criteria for Safer Luminaire Supports	Texas A & M	147,254*
15-7	Flow Modifications by Storage Loss Through Flood Plain Encroachment	Dames & Moore	99,730*
15-8	Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics	U of Michigan	274,482*
15-9	Encasement of Pipelines Through Highway Roadbeds	Byrd, Tallamy et al	30,000*
15-10	Development of a Design/Graphics Interface System	C. W. Beilfuss & Assoc	500,000*
15-11	Computer-Aided Analysis of Highway Encroachments on Mobile Boundary Streams	Simons & Assoc	246,945*
15-11A	BRI-STARS Maintenance Support and Enhancement	Hydrau-Tech	99,827
15-12	Roadway Widths for Low Traffic Volume Roads	CH2M Hill	250,000
15-13	Long-Term Performance of Geosynthetics in Drainage Applications	GRI—Drexel U	455,240
15-14(1)	Intersection Sight Distance	Midwest Res Inst	350,000
15-14(2)	Median Intersection Design	Midwest Res Inst	350,000
	AREA SIXTEEN: DESIGN—ROADSIDE DEVELOPMENT		
16-1	Effects of Deicing Compounds on Vegetation and Water Supplies	VPI	217,300*
16-2	Evaluation of Research on Roadside Development	Western States	100,000*
16-3	Erosion Control During Highway Construction	Utah State U	179,224* 70,776*
	AREA SEVENTEEN: TRAFFIC—SAFETY		
17-1	Development of Improved Methods for Reduction of Traffic Accidents	Cornell Aero Lab	247,847*
17-2	Methods for Evaluating Highway Safety Improvements	ORI	29,973*
17-2A	Methods for Evaluating Highway Safety Improvements	Jorgensen & Assoc	98,403*
17-3	Application of Traffic Conflicts Analysis at Intersections	Midwest Res Inst	190,000*
17-4	Evaluation of Traffic Controls for Street and Highway Work Zones	BioTechnology	200,000*
17-4(2)	Evaluation of Traffic Cones and Tubes for Street and Highway Work Zones	BioTechnology	125,000*
17-5	Effectiveness of Clear Recovery Zones	Midwest Res Inst	200,000*
17-6	Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones—Phase I	BioTechnology	85,069*
17-6A	Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones—Phase II	Transp Res Corp	252,277*

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
9/11/72	3/15/76	Completed—Published as NCHRP Report 202	14-3
4/15/74	3/24/76	Completed—Published as NCHRP Report 196	14-4
1/1/78	4/30/80	Completed—Published as NCHRP Report 223	14-5
9/15/81	8/31/84	Completed—Published as NCHRP Report 273	14-5(2)
6/1/82	12/31/85	Completed—Published as NCHRP Report 285	14-6
9/1/87	6/30/91	Completed—Report not published	14-7
7/6/87	10/5/90	Contract terminated—report to be included in 14-8A report	14-8
1/1/91	12/31/92	Report in review stage	14-8A
6/12/88	6/15/88	Completed—Problem statements developed	14-9
11/15/89	3/15/94	Research in progress	14-9(1)
2/28/90	3/31/92	Completed—Published as NCHRP Report 349	14-9(2)
3/12/90	9/11/91	Completed—Published as NCHRP Report 344	14-9(3)
4/15/91	7/15/93	Report in editorial and publication process	14-9(4)
5/1/91	5/31/93	Report in editorial and publication process	14-9(5)
2/1/91	1/31/93	Completed—Report to be published as NCHRP Report 360	14-9(6)
5/29/89	9/15/90	Completed—Published as NCHRP Report 334	14-10
4/15/91	3/31/93	Completed—Published as NCHRP Report 361	
6/1/89	11/30/92	Completed—Report, training manual and instructor's guide avail. for loan	14-11
12/15/65	6/14/66	Completed—Published as NCHRP Report 36	15-1
7/1/67	8/31/70	Completed—Published as NCHRP Reports 54, 115	15-1(2)
5/1/70	12/31/71	Completed—Published as NCHRP Reports 118, 129	
7/1/66	6/30/74	Completed—Phase I report publ. as NCHRP Report 108; Phase II report not publ.; for avail., see Summary of Progress Through 1988	15-2
10/1/67	12/31/68	Completed—Published as NCHRP Report 116	15-3
9/1/67	3/16/70	Completed—Published as NCHRP Report 136	15-4
8/15/67	1/10/69	Completed—Published as NCHRP Report 105	15-5
9/1/67	8/31/68	Completed—Published as NCHRP Report 77	15-6
5/1/80	1/31/82	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	15-7
5/1/82	5/31/84	Completed—Published as NCHRP Report 270	15-8
10/1/86	6/30/88	Completed—Published as NCHRP Report 309	15-9
8/1/85	11/30/88	Completed—Published as NCHRP Report 326	15-10
7/1/87	3/31/90	Report distributed to sponsors; research continued as Project 15-11A	15-11
6/1/91	11/30/93	Draft report pending	15-11A
5/1/89	10/31/93	Report in editorial and publication process	15-12
4/1/90	3/31/93	Report in review stage	15-13
6/1/92	11/30/94	Research in progress	15-14(1)
12/1/92	11/30/94	Research in progress	15-14(2)
3/1/66	4/30/72	Completed—Published as NCHRP Reports 91 and 170	16-1
10/1/67	3/31/69	Completed—Published as NCHRP Report 137	16-2
11/1/73	6/30/76	Completed—Report included in Phase II report	16-3
3/1/78	11/30/79	Completed—Published as NCHRP Reports 220, 221	
2/1/66	5/31/68	Completed—Published as NCHRP Report 79	17-1
1/10/72	6/20/72	Contract terminated—no report; research resumed under Project 17-2A	17-2
2/1/73	7/31/74	Completed—Published as NCHRP Report 162	17-2A
12/15/77	10/31/79	Completed—Published as NCHRP Report 219	17-3
1/2/78	6/30/79	Completed—Report included in NCHRP Report 236	17-4
4/23/80	9/30/81	Completed—Published as NCHRP Report 236	17-4(2)
4/1/80	4/30/82	Completed—Published as NCHRP Report 247	17-5
11/1/82	7/24/84	Completed—Research continued as Project 17-6A	17-6
10/15/84	5/16/90	Completed—Published as NCHRP Report 337	17-6A

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA SEVENTEEN (*Continued*)		
17-7	Guidelines for Converting STOP TO YIELD Control at Intersections	Bellomo-McGee Inc	200,000*
17-8	Traffic Barrier and Control Treatments for Restricted Work Zones	Texas A & M	450,000 50,000
17-9	Effect of Highway Standards on Safety	Bellomo-McGee Inc	200,000
17-10	Structural Supports for Highway Signs, Luminaires, and Traffic Signals	—	300,000
17-11	Recovery-Area Distance Relationships for Highway Roadsides	—	250,000
	AREA EIGHTEEN: MATERIALS AND CONSTRUCTION—CONCRETE MATERIALS		
18-1	Revibration of Retarded Concrete for Continuous Bridge Decks	U of Illinois	103,895*
18-2	Use of Polymers in Highway Concrete	Lehigh U	300,000*
18-2(2)	Polymer Concrete in Highway Bridge Decks	Lehigh U	30,000*
18-2(3)	Long-Term Rehabilitation of Salt-Contaminated Bridge Decks	Lehigh U	199,900*
	AREA NINETEEN: ADMINISTRATION—FINANCE		
19-1	Budgeting for State Highway Departments	Ernst & Ernst	45,000*
19-2(1)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Booz·Allen & Ham.	6,000*
19-2(2)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Ernst & Ernst	6,000*
19-2(3)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	6,000*
19-2(4)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	220,000*
19-3	Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways	Wilbur Smith Assoc	96,728*
	AREA TWENTY: SPECIAL PROJECTS		
20-1	Highway Research Information Service	HRB	455,000*
20-2	Research Needs in Highway Transportation	Tallamy/Smith	98,760*
20-3	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	Texas A & M	394,016* 200,540[a]
20-3A	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	U of Michigan	505,631* 20,000[b]
20-3B	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control—Summary Reporting	Patrick J. Athol	31,116*
20-3C	Summary of the Lodge Freeway Research	Asriel Taragin	10,183*
20-3D	Summary of All Freeway Surveillance, Communication and Control Experience	Voorhees & Assoc	40,000*
20-4	Public Preference for Future Individual Transportation	Chilton Research National Analysts	195,260* 83,911*
20-5	Synthesis of Information Related to Highway Problems	TRB	800,000[c]
20-6	Legal Problems Arising out of Highway Programs	TRB	100,000[c]
20-7	Research for AASHTO Standing Committee on Highways	Varies	
20-8	Interactive Graphic Systems for Highway Design	Control Data	49,672*
20-9	Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation	RMC Res Corp	202,579*
20-10	The Benefits of Separating Pedestrians and Vehicles	Stanford Res Inst	100,000*
20-10(2)	The Benefits of Separating Pedestrians and Vehicles	SRI International	100,000*
20-11	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Poly Inst of NY	100,000*
20-11A	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Cornell U	27,212*
20-11B	Toward Environmental Benefit/Cost Analysis: Energy-Flow Analysis (Manual)	Cornell U	140,450*
20-11C	Toward Environmental Benefit/Cost Methodology: Energy-Flow Analysis (Study Design)	The Cannon Group	14,786*
20-12	Effects of Air Pollution Regulations on Highway Construction and Maintenance	Howard, Needles et al	80,446*
20-13	Beneficial Environmental Effects Associated with Freeway Construction	Penn State U	49,965*
20-14	Monitoring Carbon Monoxide Concentrations in Urban Areas	Technol Serv Corp	99,973*
20-14A	Statistical Analysis of Ozone Data for Transportation/Air Quality Planning	SRI International	193,907*
20-15	Ecological Effects of Highway Fills on Wetlands	U of Massachusetts	152,085*
20-16	State Laws and Regulations on Truck Size, Weight, and Speed	R. J. Hansen Assoc	281,975*
20-17	Statewide Freight Demand Forecasting Procedures	Cambridge Syst Inc	73,151*
20-17A	Application of Statewide Freight Demand Forecasting Techniques	R. Creighton Assoc	193,500*
20-18	Evaluation of Highway Air Pollution Dispersion Models	SRI International	207,509*
20-19	Pedestrian Convenience and Safety on Suburban and Rural Highways	JHK & Assoc	160,000*

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
12/16/88	5/15/89	Completed—Published as NCHRP Report 320	17-7
6/1/88	6/30/93	Completed—Published as NCHRP Report 358	17-8
9/1/91	6/30/93	Completed—videotape available for loan	
2/15/92	5/31/94	Research in progress	17-9
30 months		Contract pending	17-10
27 months		Contract pending	17-11
9/1/67	12/1/69	Completed—Published as NCHRP Report 106	18-1
10/1/72	9/30/75	Completed—Published as NCHRP Report 190	18-2
1/1/78	3/15/79	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	18-2(2)
5/1/80	4/29/83	Completed—Published as NCHRP Report 257	18-2(3)
9/5/67	9/4/68	Completed—Report not publ.; summarized in NCHRP Research Results Digest 20	19-1
9/2/68	10/31/68	Completed—Working plan; not published	19-2(1)
9/2/68	10/31/68	Completed—Working plan; not published	19-2(2)
9/2/68	10/31/68	Completed—Research continued as Project 19-2(4)	19-2(3)
2/1/69	11/30/71	Completed—Published as NCHRP Report 131	19-2(4)
9/15/70	6/14/72	Completed—Published as NCHRP Report 141	19-3
3/16/64	10/31/67	Completed—Informal publication only; service is operational	20-1
4/1/66	12/31/67	Completed—Published as NCHRP Report 55	20-2
12/15/66	1/31/69	Completed—Results summarized in Project 20-3C report	20-3
1/1/67	12/31/68		
11/20/68	5/31/71	Completed—Results summarized in Project 20-3C report	20-3A
1/1/69	12/31/69		
7/1/72	9/27/74	Project terminated uncompleted; no reports prepared	20-3B
11/15/75	7/15/76	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-3C
5/15/77	12/31/78	Completed—Special publ.; for avail., see Summary of Progress Through 1988	20-3D
5/2/67	1/21/69	Completed—Published as NCHRP Reports 49, 82	20-4
5/2/67	1/2/68	Completed—Published as NCHRP Reports 49, 82	
12/15/67	[c]	Research in progress: Refer to Table III for topic reports published as NCHRP Syntheses	20-5
11/1/68	[c]	Research in progress: Refer to Tables IV and V for publications	20-6
		Research in progress: Refer to writeups in Progress by Project section	20-7
9/1/70	7/31/71	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-8
8/1/72	12/17/76	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-9
8/26/74	4/30/76	Completed—Published as NCHRP Report 189	20-10
9/1/78	7/31/81	Completed—Published as NCHRP Report 240	20-10(2)
9/1/72	5/31/74	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-11
9/1/75	11/30/76	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-11A
1/24/77	5/4/79	Completed—Report not publ.; for avail., see Summary of Progress Through 1988; sum. in NCHRP Research Results Digest 114	20-11B
4/1/77	3/31/78	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-11C
4/1/74	7/31/75	Completed—Published as NCHRP Report 191	20-12
9/3/74	8/2/75	Completed—Published as NCHRP Report 193	20-13
10/1/76	3/31/78	Completed—Published as NCHRP Report 200	20-14
9/15/79	12/18/81	Completed—Published as NCHRP Report 238	20-14A
12/1/76	12/31/79	Completed—Published as NCHRP Reports 218A and 218B	20-15
10/11/76	9/1/78	Completed—Published as NCHRP Report 198	20-16
4/1/79	7/31/80	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-17
6/1/81	1/31/84	Completed—Published as NCHRP Report 260	20-17A
3/15/79	2/28/82	Completed—Published as NCHRP Report 245	20-18
5/1/85	12/31/86	Completed—Published as NCHRP Reports 294A and 294B	20-19

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY (*Continued*)		
20-19(2)	Pedestrian Safety and Convenience on Suburban and Rural Highways—Implementation Phase	JHK & Assoc	146,218*
20-20	SHRP Pre-Implementation Research	AASHTO	500,000*
20-20(2)	SHRP Overview and Integration Planning	U of Maryland	90,000*
20-20(3)	SHRP Detailed Planning for Research on Asphalt Properties	ARE Inc	115,000*
20-20(5)	SHRP Detailed Planning for Research on Maintenance Effectiveness	Texas Res & Devel	90,000*
20-20(6)	SHRP Detailed Planning for Research on Bridge Component Protection	David G. Manning	80,000*
20-20(7)	SHRP Detailed Planning for Research on Cement and Concrete	Const Tech Lab/PCA	75,000*
20-20(8)	SHRP Detailed Planning for Research on Snow and Ice Removal	USA CRREL	73,781*
20-21	Development of an Automated Field Survey Data Collection System	ARE Inc/Cooper Tech	200,000*
20-22	Factors to be Considered by Highway Agencies in the Identification and Remediation of Hazardous Waste Sites	HMM Assoc	148,015*
20-23	Kinematic Differential GPS Satellite Surveying	GPS Services/NGS	298,793
20-24	Research Program Design—Administration of Highway and Transporation Agencies	Apogee Research Inc	125,000*
20-24(1)	Using Market Research to Improve the Management of Transportation Systems	Apogee Research Inc	199,923*
20-24(2)	Executive Management Information Systems for State Departments of Transportation	Andersen Consult	100,000*
20-24(3)	Expanding the Civil Engineering Pool	Penn State U	200,000 100,000
20-24(3)A	Civil Engineering Careers in Transportation—Outreach Program	AASHTO	100,000
20-24(4)	Senior Executive Service, Participant's Manual	Braun, Johns & Golden	25,000*
20-24(5)	Public Outreach in Transportation Management	Frank Wilson & Assoc	99,974*
20-24(6)A	Performance Measures Used by State Highway and Transportation Agencies	HUFSAM	84,891*
20-24(6)B	Business Systems Plan for Highway Engineering Information	PRODATA Inc	149,977
20-24(7)	Alternatives to Motor Fuel Taxes for Financing Surface Transportation Improvements	Cambridge Syst Inc	299,999
20-24(8)	Project 20-24 Series—Revisited	Apogee Research Inc	20,000
20-24(9)	State Departments of Transportation—Strategies for Change	Natl Acad of Pub Adm	279,855
20-24(10)	Customer-Based Quality in Transportation	Howard/Stein-Hudson	100,000
20-25	Training Needs for Highway Construction Personnel	U of Maryland	73,728*
20-25(2)	Training for Highway Construction Personnel	SNI Intl Resources	224,790
20-26	Bond and Insurance Coverages for Highway Construction Contractors	Texas A & M	99,999*
20-27	Adaptation of Geographic Information Systems for Transportation	U of Wisconsin	220,000
20-28	Hazardous Wastes in Highway Rights-of-Way	TRB	300,000
20-29	Development of a Multimodal Framework for Freight Transportation Investments: Consideration of Rail and Highway Trade-offs	Texas A & M	150,000
20-30	NCHRP—IDEA Program	TRB	1,000,000[c]
20-31	Public Policy for Surface Freight Transportation	TRB	175,000
20-32	Development of a Comprehensive Thesaurus for Transportation Research	CDB Enterprises	225,000
20-33	Facilitating the Implementation of Research Findings	—	500,000
20-34	Developing Measures of Effectiveness for Truck Weight Enforcement Activities	—	250,000
20-35	Plan for SHRP Follow-Up Studies	TRB	100,000
20-36	Highway Research & Technology—International Information Sharing	TRB	150,000
20-37	Strategic Direction for the NCHRP and Other AASHTO Research Activities	Apogee Research Inc	150,000
	AREA TWENTY-ONE: SOILS AND GEOLOGY—TESTING AND INSTRUMENTATION		
21-1	Instrumentation for Measurement of Moisture	Res Triangle Inst	35,027*
21-2	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)	Sw Research Inst	64,976*
21-2(2)	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)	SUNY Buffalo	29,953*
21-2(3)	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Evaluation)	Sw Research Inst	154,452*
21-3	Instruments for Measuring Scour at Bridge Piers and Abutments	Resource Consult Inc	305,922 339,997
21-4	Sealing Geotechnical Exploratory Holes to Protect the Subsurface Environment	Strata Engrg Corp	339,510
21-5	Determination of Unknown Subsurface Bridge Foundations	Olson Engrg Inc	350,000
	AREA TWENTY-TWO: DESIGN—VEHICLE BARRIER SYSTEMS		
22-1	Concepts for Improved Traffic Barrier Systems	Walter W. White	25,000*
22-1A	Testing and Evaluation of Bridge Rail Concepts	Texas A & M	40,000*

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
9/1/87	12/31/89	Completed—Report not publ.; agency report avail. for loan	20-19(2)
10/1/84	9/30/86	Completed—See project writeup for report availability	20-20
3/15/85	5/31/86	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-20(2)
3/15/85	1/31/86	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-20(3)
3/15/85	1/31/86	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-20(5)
3/15/85	1/31/86	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-20(6)
3/15/85	1/31/86	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-20(7)
4/12/85	2/26/86	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	20-20(8)
2/3/86	5/5/87	Completed—Published as NCHRP Report 295	20-21
11/1/86	7/1/88	Completed—Published as NCHRP Report 310	20-22
9/15/88	9/14/90	Completed—Report under NCHRP review; interim results publ. in Research Results Digest 185	20-23
5/11/87	9/30/88	Completed—Report distributed to sponsors; sum. in NCHRP Research Results Digests 170 & 183	20-24
10/1/88	9/30/89	Completed—Published as NCHRP Report 329	20-24(1)
5/1/89	10/14/89	Completed—Report distributed to sponsors; sum. in NCHRP Research Results Digest 173	20-24(2)
7/1/90	10/31/91	Completed—Phases I and II published as Report 347	20-24(3)
4/1/92	12/31/93	Research in progress	
5/1/92	8/31/93	Report in review stage	20-24(3)A
7/1/90	4/30/91	Report sent to AASHTO for publication	20-24(4)
8/1/91	1/31/93	Report in editorial and publication process	20-24(5)
8/1/91	6/2/93	Completed—Published as NCHRP Report 357	20-24(6)A
8/26/91	10/31/92	Report in review stage	20-24(6)B
3/1/92	12/31/93	Research in progress	20-24(7)
6/1/92	8/24/92	Report in review stage	20-24(8)
6/15/93	12/14/94	Research in progress	20-24(9)
12 months		Contract pending	20-24(10)
6/15/89	12/31/90	Completed—Report not publ.; agency report avail. for loan	20-25
11/1/91	5/31/94	Research in progress	20-25(2)
6/1/89	9/30/90	Completed—Published as NCHRP Report 341	20-26
3/1/90	6/30/93	Completed—Published as NCHRP Report 359 and Research Results Digest 191	20-27
4/16/90	2/1/92	Completed—Published as NCHRP Report 351	20-28
5/15/92	8/31/94	Research in progress	20-29
7/8/92	[c]	Research in progress	20-30
12/1/92	3/30/95	Research in progress	20-31
11/1/93	5/30/95	Research in progress	20-32
24 months		Contract pending	20-33
18 months		Contract pending	20-34
12 months		Research in progress	20-35
1/26/93	4/30/94	Research in progress	20-36
12 months		Contract pending	20-37
8/25/69	2/24/71	Completed—Published as NCHRP Report 138	21-1
2/1/72	1/31/74	Completed—Report not publ.; included in Project 21-2(3) report	21-2
4/1/72	9/30/73	Completed—Report not publ.; included in Project 21-2(3) report	21-2(2)
9/3/74	12/31/79	Completed—Report not publ.; agency report avail. for loan	21-2(3)
12/4/89	6/3/92	Phase I report summary in NCHRP Research Results Digest 189	21-3
5/5/92	3/31/94	Research in progress	
3/1/91	12/31/93	Research in progress	21-4
4/27/92	1/26/95	Research in progress	21-5
10/1/70	12/31/71	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	22-1
3/1/74	5/30/75	Completed—Report not publ.; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Digest 81	22-1A

TABLE 3 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY-TWO (*Continued*)		
22-2	Traffic Barrier Performance and Design	Sw Research Inst	125,000* 80,000*
22-2(2)	Multiple Service Level Highway Bridge Railings—Performance and Design Criteria	Sw Research Inst	195,000*
22-2(3)	Multiple Service Level Highway Bridge Railings—Selection Procedures	Sw Research Inst	200,000*
22-2(4)	Procedures for Testing Highway Appurtenances	Sw Research Inst	30,000*
22-3	Field Evaluation of Vehicle Barrier Systems	Calspan Corp	25,000*
22-3A	Field Evaluation of Vehicle Barrier Systems	Arthur L. Elliott	10,000*
22-4	Performance of Longitudinal Traffic Barriers	Sw Research Inst	503,954*
22-5	Develop Performance Standards & Hardware for Low Service Level Guardrail Systems	Sw Research Inst	200,000
22-5A	Warrants for the Installation of Low Service Level Guardrail Systems	Wilbur Smith Assoc	100,000*
22-6	Roadside Safety Design for Small Vehicles	Texas A & M	350,000*
22-7	Update of "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances"	Texas A & M	200,000*
22-8	Evaluation of Performance Level Selection Criteria for Bridge Railings	Texas A & M	200,000
22-9	Improved Procedures for Cost-Effectiveness Analysis of Roadside Safety Features	Texas A & M	250,000
22-10	Updated Materials for a Traffic Barrier Hardware Guide	Momentum Engrg	300,000
22-11	Evaluation of Roadside Features to Accommodate Vans, Mini-Vans, Pickup Trucks & 4-Wheel Drive Vehicles	—	200,000
	AREA TWENTY-THREE: SOILS AND GEOLOGY—PROPERTIES		
	No Projects		
	AREA TWENTY-FOUR: SOILS AND GEOLOGY—MECHANICS AND FOUNDATIONS		
24-1	Manual on Subsurface Investigations	Haley & Aldrich	75,000*
24-2	Reinforcement of Earth Slopes and Embankments	Dames & Moore	150,000*
24-3	Laboratory Evaluation of Piles Installed with Vibratory Drivers	U of Houston	200,000*
24-4	Load Factor Design Criteria for Highway Structure Foundations	VPI	459,152*
24-5	Downdrag on Bitumen-Coated Piles	Texas A&M	385,000
24-6	Expert System for Stream Stability and Scour Evaluation	U of Washington	250,000
	AREA TWENTY-FIVE: TRANSPORTATION PLANNING—IMPACT ANALYSIS		
	This area became effective January 1, 1979, and includes only those projects beginning with the FY 1981 program. Refer to Areas 7, 8, and 20 for previous projects in the realm of Impact Analysis.		
25-1	Effects of Highway Runoff on Wetlands	Rexnord, Inc.	162,189*
25-2	Predicting Stop-and-Go Traffic Noise Levels	Vanderbilt U	63,145*
25-3	Guidelines for the Development of Wetland Replacement Areas	URS Consultants	299,711
25-4	Determining Economic Impacts on Adjacent Businesses Due to Restricting Left Turns	Cambridge Syst Inc	300,000
25-5	Remote Sensing and Other Technologies for the Identification and Classification of Wetlands	Normandeau Assoc	299,770
25-6	Intersection Air Quality Modeling	Systems Applications	1,050,000
25-7	Improving Transportation Data for Mobile Source Emissions Estimates	U of Tennessee	200,000
25-8	Impact of Highway Capacity Improvements on Air Quality and Energy Consumption	TRB	100,000
25-9	Environmental Impact of Construction and Repair Materials on Surface and Ground Waters	—	200,000
25-10	Estimating the Indirect Effects of Proposed Transportation Projects	Louis Berger & Assoc	289,350

* Final contract cost. ** Addresses: Publications Office, Transportation Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418; American Association of State Highway and Transportation Officials, 444 North Capitol Street NW, Washington, D.C. 20001.

[a] NCHRP funds obligated under the $314,340 four-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, and the City of Detroit.

STARTING DATE	COMPLETION DATE	PROJECT STATUS** (for details, see latest Summary of Progress)	PROJECT NO.
1/1/72	9/30/73	Completed—Phase I and Phase II (Task 1) reports not published; for avail., see Summary of	22-2
10/1/73	3/31/75	Progress Through 1988; summarized in NCHRP Research Results Digests 84 and 102; Task 2 report publ. as NCHRP Report 153	
8/1/76	4/30/79	Completed—Agency reports on Phase I and Phase II avail. for loan	22-2(2)
1/1/79	5/31/81	Completed—Published as NCHRP Report 239	22-2(3)
5/1/79	2/28/81	Completed—Published as NCHRP Report 230	22-2(4)
1/1/74	2/15/75	Completed—Report not publ.; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Digest 76	22-3
7/1/74	12/31/74	Completed—Report not publ.; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Digest 76	22-3A
7/1/83	7/15/87	Completed—Published as NCHRP Report 289	22-4
5/1/85	1/31/89	Completed—Research continued as Project 22-5A	22-5
5/1/90	1/31/92	Completed—Agency report and User's Guide avail. for loan; summarized in NCHRP Res. Results Digest 194	22-5A
6/1/85	11/30/88	Completed—Published as NCHRP Report 318	22-6
6/1/89	8/31/92	Completed—Published as NCHRP Report 350	22-7
4/15/89	9/30/93	Report in review stage	22-8
9/1/91	8/30/95	Research in progress	22-9
1/2/91	12/31/94	Research in progress	22-10
24 months		In developmental stage	22-11
4/2/79	12/31/80	Completed—Report published by AASHTO	24-1
8/22/83	5/21/87	Completed—Published as NCHRP Report 290	24-2
1/6/86	8/31/88	Completed—Published as NCHRP Report 316	24-3
9/1/87	2/28/91	Completed—Published as NCHRP Report 343	24-4
6/15/88	12/14/93	Preliminary draft final report under review	24-5
3/15/93	3/14/95	Research in progress	24-6
2/16/81	3/16/84	Completed—Published as NCHRP Report 264	25-1
1/18/88	5/31/89	Completed—Published as NCHRP Report 311	25-2
4/1/89	9/1/93	Receipt of agency report pending	25-3
6/15/92	7/15/94	Research in progress	25-4
6/1/92	10/31/94	Phase I complete; interim report available on loan	25-5
2/1/93	1/31/96	Research in progress	25-6
12/1/93	2/28/95	Research in progress	25-7
3/1/93	8/1/94	Research in progress	25-8
18 months		Contract pending	25-9
12/1/93	5/31/95	Research in progress	25-10

[b] NCHRP funds obligated under the $70,000 five-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, the City of Detroit, and the University of Michigan.

[c] Continuing activity. Amount shown is for latest fiscal year in which funding was provided.

[d] NCHRP funds obligated under the $150,000 five-way agreement among the National Asphalt Pavement Association (NAPA), AASHTO, FHWA, U.S. Army Corps of Engineers, and Federal Aviation Administration (FAA).

[e] NCHRP funds obligated under the $30,000 three-way agreement among AASHTO, FHWA, and U.S. Army Corps of Engineers.

TABLE 4
EXAMPLES OF UTILIZATION OF NCHRP RESULTS*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
1-1	Reports 2, 2A	Illinois Div. of Hwys., Bur. of Res. and Devel.	In studies of existing pavements and the rehabilitated AASHTO Road Test project at Ottawa, Ill. Particular use made of recommendations for experimental designs, measurement programs, and data processing analysis.
		Conn. DOT	To design experimental pavement projects.
1-2	Report 7	N. Y. DOT	To develop a flexible pavement performance equation; in use June 1968.
		Tallamy, Byrd,—	In study of highway maintenance quality levels for Ohio Dept. of Hwys.
1-3(2)	Report 22	Conn. DOT	In evaluating flexible experimental pavements.
1-3(3)	Report 35	Conn. DOT	In evaluating flexible experimental pavements.
1-4	Report 10	Conn. DOT	In analyses of data from experimental pavements.
1-4(2)	Report 30	Conn. DOT	In evaluating flexible experimental pavements.
1-5	Report 21	Conn. DOT	In evaluating flexible experimental pavements.
1-5(2)	Report 76	N. Dak. SHD	Major equipment purchase based on successful use of similar equipment in conduct of project.
		Conn. DOT	In evaluating flexible experimental pavements.
1-7	Report 37	Nat'l. Hwy. Safety Bur.	In preparation of a *Highway Safety Program Manual* for issuance to the States.
		92nd Cong., 1 Sess.	House of Representatives subcommittee hearings on highway safety and skidding.
		Conn. DOT	As justification to establish skid test program in Connecticut.
1-8	Agency final report	Consult. for USN and USAF	Development of new approach to pavement design for heavy aircraft loadings; used for redesign of Salt Lake City runway to accommodate B747 aircraft and in design of runway, taxiways, and aprons at Air Force Plant No. 42 near Palmdale, Calif., where design load is 500 tons (gross) from B2707 (SST) configuration.
1-9	Report 61	Calif. Div. of Hwys.	In evaluation of proposed State legislation regarding use of studded tires.
		Conn. DOT	In providing documentation for studded tire legislation.
1-10	Agency final report	Consult. for USN and USAF	See Project 1-8.
1-11	Agency report	U.S. Forest Serv.	In preparation of an Engineering Technical Report evaluating several commonly accepted pavement design methods, as to their applicability for design of pavement systems for Forest Service roads.
		AASHTO	Partly published as *Interim Guide for Design of Pavement Structures, 1972*
1-12	—	92nd Congress, 1st Sess.	House of Representatives subcommittee hearings on highway safety and skidding.
	Report 154	Conn. DOT	As background information on skid-testing program.
1-12(2)	—	92nd Cong., 1 Sess.	See Project 1-12.
	Report 151	Conn. DOT	As background information on skid-testing program.
		N. Y. DOT	Leans heavily on the suggestions presented when purchasing or altering skid trailers and when modifying operational procedures.
		ASTM	As basis for updating ASTM Method E274.
1-12(3)	—	92nd Cong., 1 Sess.	See Project 1-12.
1-14	Agency final report	Va. DOT	Safety Committee reviewed agency recommendations for improvements at high accident site, with resulting request for FHWA approval as an Interstate Safety Project.
1-17	Report 224	Washington DOT	In the design of pavement rehabilitation programs.
		Japan Road Contractors Association	Translated in Japanese.
1-18	Report 228	World Bank	Basis for designing an international calibration exercise for road meters.
1-19	Agency interim report	FHWA	As input to FHWA-AASHTO Long-Term Pavement Monitoring Program documents.
		Illinois DOT	As reference for identifying concrete pavement distress.
1-21	Agency draft guide, "Specs. for Joint Repair"	FHWA	As input to internal publication titled, "Construction Handbook on PCC Pavement Rehabilitation."
		Penn. DOT	As a guide for developing policies and repair techniques.
2-5	Reports 13, 111	One State (unkn.)	To replace outdated material in AASHTO book, *Urban Freeway Design.*
2-5A	Report 111	AASHTO	In draft of proposed AASHTO publication, *A Policy on Arterial Highways in Urban Areas.*
		W. W. Rankin, I.T.E.	In preparing textbook on traffic engineering.
2-6	Report 63	E. L. Grant, W. G. Ireson	In textbook, *Principles of Engineering Economy.*

* Project titles, as well as project status, are given in Table 3. Publication titles are given in Tables 5, 6, and 7.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
2-11	Report 122	World Bank	For teaching purposes by the Economic Development Institute of the International Bank for Reconstruction and Development.
2-12	Agency rep. and Rep. 111	Federal Supply Serv., Gen. Serv. Adm.	Vehicle operating cost data applied in review of Govt. employee automobile costs.
	Agency report	J. Leisch & Assoc.	As an aid in conducting a planning-design course for the South Carolina SHD in coordination with the Governor's Safety Program.
		AASHTO	Published by AASHTO as *A Manual on User Benefit Analysis of Highway and Bus Transit Improvements.*
		Colorado SHD	As a partial basis for development of the State's "Benefit/Cost Analysis Manual."
3-2	Reports 9, 29	Illinois Div. of Hwys., Bur. of Traffic	In a FAI 80 Motorist Communication project. Also, more emphasis being placed on influence of pedestrians on signal timing, because signals in small cities are almost always in the CBD where there are many pedestrians.
3-4	Reports 6, 40	Calif. Div. of Hwys.	Source of background information for highway and law enforcement officials facing problem decisions on location of disabled or stopped vehicles.
3-5	Reports 3, 32, 73, 124	D.C. Dept. of Hwys. and Traffic	Incremental travel cost technique applied to a comprehensive determination of existing effectiveness of operation in D.C. traffic signal system. Annual incremental travel costs in D.C. system were estimated and used in benefit/cost analysis of traffic signal system improvement alternatives.
		Minn. DOH	Steps taken toward implementation of the delay difference offset technique in an existing signal network.
		Calif. Div. of Hwys.	Source of information to supplement and improve the effectiveness with which the Division can carry out its program of reducing delay to the motorist. Also of value in designing innovative signals; in fact, the Division engaged the principal investigator on a consulting basis to help simulate different levels of traffic for a project under design in Riverside County.
	Agency final report	Goodell, Grivas and Assoc.	Obtained contract to use model described in report on a network in Detroit.
3-7	Reports 78, 117 and "Illustrative Recording of Traffic Noise"	Hwy. Depts., FHWA offices, universities, consulting firms, County Bd. of Educ.	Demand for the tape has been large, and loan copies have been circulated widely. Although the principal use of the tape has been educational in nature, one County Board of Education was so impressed with the noise differential between open and closed window situations that consideration was given to installation of air conditioning and storm windows for school buildings adjacent to freeways.
		Georgia SHD	Noise design guide used in design of urban freeway system.
		Minnesota Legislature	For demonstration purposes in hearings by House "Transportation" Committee, and Senate "Highways" and "Natural Resources and Environment" Committees. Both Senate committees took favorable action on a Truck Noise Control bill patterned after the California law.
		Virginia DOH	To evaluate noise for several proposed highways and to make subsequent explanations to the public on the impact of the noise on the community. One instance involved I-195, a six-lane depressed highway in a residential area of Richmond. Using the computer program from *Report 78,* peak-hour traffic was used to project the noise levels; comparisons were made with actual readings taken in the area. Another case involved projecting noise levels on I-66 in the vicinity of Washington, D.C., to determine if they would be within an acceptable limit. Revisions were made in the cross sections where estimates exceed the acceptable limit. The Department estimates that almost $18,000 was saved by doing the evaluation work in-house, rather than contracting it. Annual savings of $50,000 to $75,000 have been forecast in the instance of standard evaluations of major projects.
		Arizona cons. firm	In design and location of a 4.5-mi segment of I-10 (Papago Freeway) traversing a high-density area of downtown Phoenix. Recommendations made are expected to substantially reduce noise levels in areas adjacent to the Freeway.
		Natl. Assn. of Homebuilders	In development of a *Builders' Acoustical Manual* that includes guidelines for prediction of site noise due to traffic.
		Missouri SH Comm.	Highway traffic noise simulation program used to establish noise projections on new project designs.
		FHWA	In developing highway noise level standards PPM 90-2, "Interim Noise Standards and Procedures for Implementing Section 109(I) 23 U.S.C."
		Louisiana DOH	As primary texts in a "noise school" for parish (county) engineers.
		AASHTO	As source documents for new (1974) publication, "Guide on Evaluation and Attenuation of Traffic Noise."
	Report 117	Howard, Needles, et al.	Model for predicting highway traffic noise validated under contract to a state highway department.
		Express Hwy. Res. Fdn. (Japan)	Abridgment (8 pp.) published in April 1972 issue of *Expressways and Automobiles* (in Japanese).

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Colorado DOH	Projected noise study based on a U.S. DOT program developed directly from this report, considered to represent the best study procedure from available empirical and theoretical research on highway noise.
		Minnesota DOH	Predictions for use in design of I-35W noise barrier in S. Minneapolis.
	Agency final rep. draft	Envir. Protection Agency	In evaluating alternatives for truck noise emission regulations.
	Agency final rep.	Nat. Bur. Stand.	Published a form of the Noise Prediction Nomogram adapted to an "L-equivalent" measure.
		Md.-Natl. Cap. Park and Plan. Comm.	Found to be useful and quite accurate as a tool in preparation of land-use plans.
	Rep. 78, 117, 144	Conn. DOT	As a basis for noise analyses.
3-8	Report 50	Orange Co. (Calif.) Traf. Eng. Council	Extensive use as best available source of information for preparation of warrants for installation of protective devices at rail-grade crossings.
		Illinois Div. of Hwys., Bur. of Design	In a continuing program toward grade crossing safety, with particular use seen for portion dealing with crossings where flashing light signals—with or without gates—are not warranted.
		Conn. DOT	Source reference for Railroad-Highway Safety Grade Crossing Program.
3-9	Report 84	Calif. Div. of Hwys.	Recommendations used on Freeway Surveillance and Control Project (Los Angeles), involving expenditure of about $8 million in three years.
3-12	Report 123	Transp. Syst. Center	Information on fixed highway signing principles particularly helpful in providing control signals to pilots at Kennedy International Airport (New York).
	Agency report	Street Name Signing Comm., ITE	As background information in review of street name signing applications to meet motorists' needs.
3-12(2)	Agency final report	AAA Found, for Traffic Safety	As the primary reference for preparation of the pamphlet, "Improving Road Guide Signs . . . What Can You Do About It?"
3-13	Report 93	City of Waco, Tex.	Plans to incorporate in subdivision and zoning regulations many of the controls recommended as a means of protecting facility capacity and safety.
3-14	Film, "Relief for Tired Streets"	New York DOT	To encourage municipalities in State to apply traffic engineering solutions to their congestion problems.
3-15	Agency report	Consultant	Using nomographs and incorporating the research findings into some current projects.
3-16	Agency report	FHWA	As support material in resolving an operations problem.
3-18(1)	Agency interim report	City of Lincoln, Nebr.	In design of digital computer-controlled traffic control system to supervise 250-300 signalized intersections.
	Agency report	New Zealand Ministry of Works	To reduce hardware costs by applying greater software capabilities to computer-controlled traffic signal operations.
		New York DOT	As background and design evaluation for a centralized computer traffic surveillance and control system in the Northern Long Island Corridor.
3-18(2)	Agency report	Dade Cty., Fla.	As basis for operational changes at selected locations.
3-18(3)	Agency interim report	FHWA	A summary report presenting results of a survey of traffic signal system design and operation practices was used in development of a FHWA training program for traffic engineering personnel.
	Agency report	Texas SDH and Pub. Transp.	Report selected as a textbook for a course for city and state traffic engineers in traffic signal system design.
3-19	Agency report	Utah DOT	In highway analysis.
3-20	Agency report	FHWA	To develop interest in warrant improvement within Signals Subcommittee of National Advisory Committee on Uniform Traffic Devices.
3-21	Agency report	N.J. Tpk. Auth.	In conjunction with research project studying visual effects of variable-message signs.
3-22A	Report 232	Texas SDHPT	Text material for the "Freeway Management Operations Workshop." Participants included SDHPT district personnel, state and city traffic engineers, and state and city police.
3-23	Agency report	AMV Australia	In developing a manual for design of signalized intersections for Road Safety and Traffic Authority, Victoria, Australia.
		FHWA	To amend Sections 4B-8, 4B-10, 4B-11, and 4B-12 of the *Manual on Uniform Traffic Control Devices.*
3-25	Agency final report	Consultant	To determine the safety impacts of lower design standards related to construction and maintenance activities in the context of energy conservation.
3-26	Agency interim report	City of Edmonton, Alberta, Can.	In designing noise-barrier walls.
	Agency final report	County of Sacramento Plng. & Commun. Dev. Dept.	As a supplement to the FHWA Highway Noise Prediction Model used to conduct environmental analyses of proposed highway projects.
3-27	Report 233	Fuel Efficient Traffic Signal Mgmt. Program	In their Bulletin, readers were referred to various Report figures that would aid in determining timing parameters for traffic-actuated controllers.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
3-28	Unpublished by NCHRP. TRB Circular 212	Polytechnic Inst. of N.Y.	Highway capacity workshop materials.
3-28B	TRB Special Rpt 209	States, FHWA, Universities	As primary resource document for highway capacity analysis and as basic document for training programs and computer software.
3-31	Report 288	FHWA/NHI	Material incorporated into National Highway Institute training course.
4-3	Reports 12, 15, 65, 66	ASTM	Basis for development of C671, "Tentative Method of Test for Critical Dilation of Concrete Specimens Subject to Freezing," and C682, "Resistance of Aggregates to Freezing."
4-6	Reports 74, 74A, 74B	Conn. DOT	As backup in developing paint systems for highway bridges.
4-7	Report 164	AASHTO	Recommendations for consideration of fatigue of reinforcement in concrete highway bridges incorporated in 1975 as provisions in AASHTO "Standard Specifications for Highway Bridges."
4-8(3)	Agency final report	Arizona DOT	To revise Department's asphalt paving mix design criteria
	Report 246	AASHTO	Test procedure adopted by AASHTO Subcommittee on Materials and published in AASHTO *Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part II,* 1986, as T283-85, "Resistance of Compacted Bituminous Mixtures to Moisture-Induced Damage."
4-11	Agency interim report	Fed. Aviation Admin.	Tentative guidelines for selection and installation of plastic pipe were used to reduce time and funds required for a research project on plastic pipe for airport drainage.
		State Hwy. and Transp. Materials Engrs.	On basis of advisory panel member comments that information in report would be useful to practicing engineers, report was distributed to members of AASHTO Operating Sub-Committee on Materials.
		U.S. Forest Serv.	Distributed to each regional office on basis of headquarters office determination that it will prove of use to engineers involved in design of road and sanitary sewer projects.
		Albuquerque, N.M.	In deciding on use of certain materials for city sewers.
		Illinois DOT	In preparing specifications and purchase of plastic pipe.
	Report 225	Soil Conservation Service, USDA	As a guide in developing a technical release on plastic piping materials for use by field personnel in planning and design of plastic pipe systems.
		AASHTO	In developing materials' specifications.
5-4	Report 20	AASHTO Stdg. Comm. on Engrg. and Opers.	Input (with Report 77, Proj. 15-6) to the March 1969 publication, *Informational Guide to Roadway Lighting.*
5-5A, B	Agency report	DeLeuw Cather	Findings incorporated in research study.
5-7	Report 130	Ohio DOH	Reference source of current and complete information on individual delineation techniques.
		Org. for Econ. Coop. and Devel. Res. Group C-8	In preparing report on Visual Effectiveness and Durability of Road Markings, Reflectors, and Delineators.
		FHWA	In a report of two FHWA Delineation Conferences, summarized in four parts for group presentations, NCHRP Project 5-7 is described as the most comprehensive delineation research in recent years and its report as giving the best available description of the guidance function of delineation.
5-9	Report 256	AASHTO	Referenced in "An Informational Guide for Roadway Lighting."
6-1	Report 19	California Div. of Hwys.	Source material and bibliography simplified literature search and saved much valuable time. Results incorporated in planning and design of new projects.
		Conn. DOT	In developing deicing chemical policy.
6-2	Report 4	Calif. Div. of Hwys.	See Project 6-1.
		Conn. DOT	In developing snow and ice policies.
6-3	Report 16	Calif. Div. of Hwys.	See Project 6-1.
		Natl. Flaxseed Processors Assn.	Advertising (*Civil Eng.,* Feb. 1966) highlighting research results in stating ". . . considering both the economy and performance, the best results by far were obtained by vegetable oil, and particularly linseed oil solutions."
		Conn. DOT	In developing treatments to prevent deterioration of PCC bridge decks.
6-4	Report 23	Iowa SH Conn.	Constructed bridge with galvanized reinforcing bars in one-half of deck. This follows recommendations to the effect that more field evaluation is required of zinc, nickel, and asphalt-epoxy coatings.
6-5	Report 27	Calif. Div. of Hwys.	See Project 6-1.
6-8	Report 1	Calif. Div. of Hwys.	See Project 6-1.
		U.S. Park Serv.	Techniques used by consulting engineering firm for deck repair of Memorial Bridge, Washington, D.C., depended heavily on reported results.
6-10	Agency reports	Calif. Div. of Hwys.	In preparation of plans for two sections of US 50 from Riverton to the Nevada State line. Design

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			consideration given to those factors considered vital to increased safety and reduced maintenance at interchanges under the adverse conditions of snow and ice.
	Report 127	Conn. DOT	As source reference for snow and ice policy.
	Report 127 and 35-mm slides	New York DOT	Region 5 duplicated a loan set of 35-mm slides illustrating Appendix J for showing at Region meetings. They have proven helpful for both design and maintenance activities.
7-4	Report 89	Illinois DOT, Bur. Planning	Findings have been found useful, and practice has been modified to conform with them.
7-7	Report 64	Ohio DOH	Implemented several recommendations pertaining to rest areas with maps and other information of interest to motorists, signing conformity, service patrols, patrol aircraft, and medicopter service.
7-8	Report 133	Conn. DOT	As a basis for noise analyses.
		Dept. of Eng., Univ. of Wisconsin	As a reference text for an extension course entitled "Data Collection and Evaluation Techniques for Transportation Systems Management."
7-10	Agency interim report	Oregon County Transit Dist.	In preparation of an energy contingency plan.
	Agency report	U.S. Environmental Protection Agency	To brief members of Senate Public Works Committee on the state of the art of transportation controls.
	Report 169	N.Y. State DOT	As examples of how to develop possible air quality packages for seminars to state and metropolitan planning organization transportation planners.
		Hawaii DOT	As a basic guide for the State's TSM plan.
7-10(2)	Agency final report	N.Y. State DOT	Same as Project 7-10
7-11	Report 263	FHWA	Material for transportation planning methods course.
8-3	Agency report	Arizona HD	Source material for decisions based on consumer sensitivity to the various factors considered in trip making.
8-4	Report 96	Dept. of Eng., Univ. of Wisconsin	As a text in short course on Urban Transportation Planning.
8-5	Report 121	Dept. of Eng., Univ. of Wisconsin	As a text in Traffic Engineering Seminar.
8-5A	Report 121	G. E. Pidcock Co.	To forecast volume of traffic generated by proposed subdivisions and developments.
8-8(3)	Agency interim report	Iowa SH Comm.	In development of an action plan in conformance with FHWA PPM 90-4.
		Delaware DOH & T	In development of an action plan in conformance with FHWA PPM 90-4.
	Agency report	N.Y. DOT, Transp. Planning Div.	In preparation of a synthesis report giving background to regional personnel responsible for citizen participation. Also useful in development of N.Y. State Action Plan.
		FHWA	Assisted in development of PPM 90-4.
		Michigan DOT	Assisted in preparation of the state's Action Plan.
	Report 156	Nat'l. Inst. for Road Res., S. Africa	In developing similar procedures in South Africa.
		Conn. DOT	In preparing environmental impact statements.
8-10	Report 155	Harvard Professor	In preparing a textbook.
8-11	Agency report	Illinois DOT	Portions incorporated into a manual on assessment of ecological impacts from highways for distribution to district engineers and others doing work for the department.
8-12	Agency report	FHWA	By regional transportation planners to provide technical support to the states.
		Princeton Univ.	In graduate courses.
8-12A	Agency final report and User's Guide	NYS DOT	User's Guide distributed to all regional planning offices to provide a quick-response capability for estimating travel demand.
		Consultant to Nat'l. Inst. for Transport and Road Res., S. Africa	To develop guidelines for undertaking urban transportation studies.
	Reports 186 and 187	Harvard Univ.	As course material.
		Univ. of Wisconsin Extension	As course material in conjunction with the NCHRP training material.
		FHWA, Urban Planning Div.	Practical applications by state and local agencies were documented in a report entitled "Application of Quick Response Travel Estimation Procedures." Site impact, corridor, and system analyses were included.
	Report 187,	FHWA, National Hwy.	As the basic training aid for short courses. More than 1,000 state and local officials have participated

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	Training Materials, and microcomputer applications	Inst., State/Local Agencies, & Numerous Universities	in 35 courses sponsored by FHWA's Urban Planning Div. in cooperation with MHI. Six additional courses are planned for next year.
8-16	Agency final report Appendix, "Transportation	Am. Public Transit Assoc.	Testimony on proposed DOT regulations to implement Sec. 504 of the Older Americans Rehabilitation Act.
	Services for the Transportation Disadvantaged"	U.S. Congress	Evaluation of DOT regulations to implement Sec. 504 of the Older Americans Rehabilitation Act.
8-16	Report 208	Division of Mass Transp., Caltrans	For determining alternatives for service implementation.
	Report 209	Division of Mass Transp., Caltrans	In development of transportation services for the transportation disadvantaged.
	Report 210	Division of Mass Transp., Caltrans	As a resource document for over-all planning activities.
	Report 211	Division of Mass Transp., Caltrans	To restructure and reorient marketing efforts.
8-20	Preliminary Draft Rpt.	Nat'l Inst. for Transport & Road Res., S. Africa	To design traffic counting program for four provinces of South Africa
8-23	Agency report	North Central Texas Council of Govts.	In quarterly report on DOE contract, the projected automotive operating costs of gasoline and non-gasoline engines.
8-25	Agency report	Montana Dept. of Commerce	To redesign approach of an analysis of intercity buses.
8-26	Report 255	FHWA	As a primary reference for training course material (National Highway Institute).
8-27	Report 262	New York MTA	To develop handicapped ridership for rail system.
9-3	Report 38	Ford Motor Co.	Saved countless hours of search and survey by state-of-the-art section on highways joint and crack sealing materials and methods. Useful in further understanding various design, construction, and maintenance problems, in analyzing specific failures, and in adapting future developments in highways to their industrial and other roadway problems.
10-1	Report 17	North Dakota State Univ.	Basic text for a course in statistical quality control taught to both undergraduates and a sizable number of engineers, the majority of the latter being highway department employees.
		Illinois Div. H, Bur. Materials	In conjunction with FHWA sigma bank, and data developed by our field testing, to develop special provisions covering statistical acceptance of bituminous concrete pavement.
		Conn. DOT.	As reference by Specifications Division.
10-2	Report 34	Illinois Div. H, Bur. Materials	In conjunction with supplementary materials, as a basis for recommending and/or limiting stockpiling methods to be included in the policy being developed for aggregate inspection and acceptance.
10-2A	Report 69	Conn. DOT	In developing statistical specifications.
10-5	Reports 14, 13	Conn. DOT	In establishing nuclear density and moisture tests in soils.
10-6	Report 52	Illinois Div. H, Bur. R&D	Considering a trial of recommendation for use of nuclear pellet technique for measuring pavement thickness.
10-8	Agency final report	Penn. DOT	The Ohio State ultrasonic gauge, several eddy current proximity gauges, and additional pachometers used with the new statistically based acceptance specifications to reduce over-all construction costs.
10-9	Res. Results Digest 48	U. Minn. and Minnesota DOH	In seminars conducted throughout Minnesota to train city and county personnel in use of the pavement surface condition rating system.
10-10	Report 201	FHWA	As a basis to prohibit use of electroslag welding in main structural tension members on federal-aid projects and to institute a program of rigorous inspection in existing structures welded by the electroslag process.
10-17	Report 274	ASTM	Adopted test method as ASTM Standard D 4867, Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures
10-18	Report 258	Concrete Construction Magazine	A condensed version of this report appeared in the August 1984 issue. The magazine is distributed nationally to engineers and contractors by a number of State ready-mixed-concrete associations.
10-20	Report 248	AASHTO	Unconfined elastomeric bearing specifications adopted in toto in the "1985 Interim AASHTO Standard Specifications for Highway Bridges."
10-21	Synthesis 86	Delaware River Joint Toll Bridge Comm.	Information of direct relevance in decision regarding replacement of bridge deck on a major bridge.
11-1(6)	Report 92	N. Mex. SH Comm.	In settling negotiations for purchase of an airport.
11-3	Report 56	Indiana SH Comm.	Rated as "excellent" by Land Acquisition Division, which requested extra copies for use in development of new work in area of responsibility.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Illinois Div. H, Bur. Rt.-of-Way	Most of the principles set forth have been in practice. Land Economic Study unit conducted a study according to the report recommendation for one method of analysis of the value of scenic easements.
12-2	Report 83	California Div. of Hwys.	Own research project on "Analysis, Design and Behavior of Highway Bridges" used both basic knowledge and example of a well-devised rational approach to further simplify the proposed formulas and criteria recommended as revisions to the AASHTO Specifications, and to consolidate and authenticate the proposed criteria by further model and prototype verification of analytically obtained values.
12-5	Report 90	California Div. of Hwys.	Confirmed the Division's present practices, gave reassurance that its long-term investment in prestressed concrete structures is sound, and answered the question as to practicability of protective coatings.
12-7	Report 102	Naval Ship Res. and Devel. Lab.	Limited portions used in a technical report entitled "Some Observations on the Fatigue Behavior of Specimens and Structures."
		Illinois DOT, Bur. Design	Findings have been found useful, and practice has been modified to conform with them.
		Conn. DOT	To change bridge design parameters in order to reduce fatigue cracking.
	Report 147	AASHTO	Fatigue specification recommendations adopted in total in "1974 Interim AASHTO Standard Specifications for Highway Bridges."
		Conn. DOT.	To accomplish bridge design modifications intended to reduce fatigue cracking.
		Am. Rwy. Eng. Assn.	To develop modifications to fatigue provisions in AREA Specifications (1975).
12-8	Report 86	Canadian Stds. Assn.	Committee on Design of Highway Bridges used results in updating standards for bridge railing loads.
		Conn. DOT	To provide backup information for current bridge-rail design.
12-11	Report 165	Minnesota DOT	In selecting waterproof membrane systems for field evaluation.
12-15(3)	Report 227	Wisc. DOT Iowa DOT Ill. DOT Kans. DOT Pa. DOT Conn. DOT	To retrofit fatigue-susceptible structural details in welded steel highway bridges.
12-19A	Report 244	Kansas DOT	As reference for guidance in selecting concrete sealers.
		Commercial product manufacturers	As a standard for establishing their own specifications on specific products.
		Industrywide	Results of study have caused many states and industry to be more concerned with technical support on claims made for the performance of concrete sealers. Test procedures in report have become an unofficial standard.
12-22	Report 276	AASHTO	Subcommittee on Bridges and Structures adopted recommendations for thermal gradient design as a Guide Specification to the 1988 Interim AASHTO "Standard Specifications for Highway Bridges."
12-24	Report 287	AASHTO	Subcommittee on Bridges and Structures adopted recommended changes to the load distribution requirements for multibeam bridge superstructures in the *Standard Specifications for Highway Bridges* in 1988.
12-27	Report 321	Alfred Benesch & Co.	The guidelines outlined in the report were used to ensure sound weld quality when repairing fatigue cracks in the girder webs of four welded-plate-girder railroad bridges.
12-28(1)	Report 301	AASHTO	The second phase from Project 12-28(1) developed a comprehensive bridge load capacity specification based on the results of Projects 10-15(1) and 12-28(1). The Subcommittee on Bridges and Structures adopted the load capacity evaluation guidelines as a Guide Specification in 1988.
12-28(3)	Report 299	AASHTO	The fatigue design guidelines were adopted by the Subcommittee on Bridges and Structures as a Guide Specification in 1988. The fatigue evaluation guidelines were adopted as a Guide Specification in 1989.
12-32	Report 297	AASHTO	The corrosion protection requirements for reinforcing steel in the *Standard Specifications for Highway Bridges* were revised by the Subcommittee on Bridges and Structures in 1988 as a result of the recommendations included in the report.
12-34	—	AASHTO	Subcommittee on Bridges and Structures adopted complete revision and replacement for Division II—Construction of the *Standard Specifications for Highway Bridges* in 1990.
12-35	—	AASHTO	Subcommittee on Bridges and Structures adopted complete revision and replacement for Sections 4, 5, and 7 (Foundations, Substructures, and Retaining Walls) of the *Standard Specifications for Highway Bridges* in 1990.
13-1	Report 26	Delaware SHD	In a study of highway maintenance management, Advanced Management Planning, Inc., recommended use as a guide in establishing equipment rental rates.
14-1	Report 42	Minnesota DOH	Of considerable assistance to the investigators in the Maintenance Program Budget Pilot Study,

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			which includes a determination of the sets of road characteristics to which quality and quantity standards codes should be assigned.
		Washington State SH Comm.	In development of a unit maintenance expenditure index for the State.
		Ohio Dept. of Hwys.	In a study to develop a forecast of maintenance needs for the 1970-80 decade and compare it with the trends in highway maintenance needs for the U.S. as a whole and for the Northeast region in particular.
		Conn. DOT	In establishing Maintenance Management System.
14-5	Report 223	Penn. DOT	To determine tradeoffs between various maintnenace activities for resource allocation. Allowing gross to grow 6 in. higher before cutting saves $600,000 a year that may be used to reduce edge-drop-off.
15-1	Report 36	Commercial firm	In formulating a design for a new fiberglass guardrail system.
15-1(2)	Report 54	Federal and State agencies	In planning, design, construction, maintenance, replacement of guardrails and median barriers.
		American Iron and Steel Inst.	Recommendations on standardization of guardrail hardware by the Highway Task Force of the Institute's Sheet Committee to include use of the flat washer illustrated on page 29 of *Report 54.*
		Illinois Div. of Hwys.	Included in highway design policies and standards by Bur. of Design. New Bur. of Maintenance standards for guardrail and median barriers adapted from report. Bur. of Traffic comments highlight *Design Manual* or *Highway Standards* areas that could be improved by the findings; the warranting of trial installations of various types of median barriers, for reasons of both safety and economy; and the value of certain information as a tool to determine whether to remove or upgrade existing installations.
		Nevada DOH	In evaluating acceptability of the Department's design criteria and standards.
	Report 115	Illinois DOT, Bur. Design	Findings have been found useful, and practice has been modified to conform with them.
		Conn. DOT	As a basis of guardrail systems currently used in Connecticut.
	Report 118	New York DOT	As a vital supplement to a recently prepared design manual covering policies, procedures, and standards. Design guide refers to report for further information.
15-2	Report 108	Connecticut DOT	On trial basis, used the design technique developed for channels lined with riprap. Major relocation of a stream and tributaries having a design flood discharge of 3,900 cfs from a drainage area of 7.3 sq mi was involved. Saving from use of riprap instead of paving was estimated to be more than $90,000. Evaluation of the effectiveness of the treatment is continuing, especially observation of behavior during and after any significant storms.
		Wisconsin DOT	Channel design procedure applied to ditches along the Lake Wissota—Cadott Road in Chippewa County, previously subject to erosion, but none has occurred since use of riprap according to the procedure.
		Kansas SH Comm.	As basis for publication, "Design of Stable Roadside Channels."
		Minnesota DOH	To design riprap for a stream relocation at Moose Lake. Riprap erosion protection functioned as planned during rainstorms providing discharges approximating the design value of 275 cfs.
		Colorado DOH	Method to size riprap protection included in Ch. 8 of Design Manual.
		Soil Conserv. Serv., U.S. Dept. of Agr.	Recommendations used in preparation of *SCS Tech. Release No. 59,* "Hydraulic Design of Riprap Gradient Control Structures."
	Report 108 and agency draft	Hydr. Br., Bridge Div., FHWA	As source documents for "Stable Channel Designs"; design procedures for riprap linings developed principally from Report 108.
	Report 108 and agency report	Consultant, Madrid, Spain	Riprap design procedure applied to channels along motorways in Spain.
15-4	Report 136	Indiana SH Comm.	Used National Small Streams Data Inventory compiled during project as an additional check on flood flow estimates.
15-6	Report 77	AASHTO Stdg. Comm. on Hwys.	Input (with Report 20, Proj. 5-4) to March 1969 publication, *Informational Guide to Roadway Lighting.*
		California Div. of Hwys.	Instrumental in setting the standards for California and aiding in developing the most satisfactory breakaway base. The California research, without that done under NCHRP, reportedly would have cost well over $100,000 to develop or affirm preliminary designs of this type.
		Conn. DOT	As a basis for breakaway luminaires for highway lighting.
15-7	Agency final report and User's Manual	Wyoming Hwy. Dept.	As reference for guidance in determining flow modifications caused by storage losses on encroached flood plains.
16-1	Report 91	California Div. of Hwys.	Appendix D ("Effects of Salts on Plant Biota") is the most complete dissertation on soil salinity and salt-tolerant plants in the Division's reference files.
		U.S. Government	As a primary reference in formulating the National Environmental Policy Act of 1969 and Executive Order 11514 on "Protection and Enhancement of Environmental Quality."

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Conn. DOT	In preparation of environmental impact statements.
16-3	Agency report	Iowa DOT	In a training program on erosion control for state personnel.
	Report 221	Hittman Assoc. Inc.	Information and illustrations used in a field manual for the Office of Surface Mining, U.S. Dept. of Interior.
	Reports 220 and 221	Utah DOT Park City, Utah	To develop a manual. Developers are required by city ordinance to comply with provisions set forth in the reports.
17-1	Report 79	Robley Winfrey	In development of college textbook, *Economic Analysis for Highways.*
		Calspan	As starting point for a Tri-Level Accident Research Program for NHTSA and the Motor Vehicle Mfrs. Assn.
		Min. of Transp., Brazil	Translated into Portuguese.
17-2A	Agency report	S. Dak. DOT., Div. of Hwys.	To assist in evaluating safety improvements accomplished under an ongoing safety program.
	Report 162	Northwestern Univ.	As a reference and teaching aid in a graduate course in highway safety programming.
		Office of Highway Safety, FHWA	By staff serving as instructors for a series of regional seminars on evaluation of safety improvements.
17-3	Report 219	FHWA Office of Traffic Operation	As source document for FHWA's Positive Guidance series on planning and collection of field data.
		The Israel Nat'l Council for Prevention of Accidents	The final report and a training film prepared to this research were used in a pilot project to study conflicting traffic movements at intersections.
17-4	Report 236	FHWA, Nat'l Comm. on Uniform Traffic Control Devices	As a basis for changes in a Uniform Manual of Traffic Control Devices, Part VI, Traffic Control for Street and Highway Construction and Maintenance Operations
18-2(3)	Report 257	Penn. DOT	To develop a field trial for the deep polymer impregnation of a bridge deck with the "deep grooving technique."
19-2(4)	Report 131	Off. of R&D, FHWA	As a primary reference in training courses on managing highway maintenance.
19-3	Report 141	Nat'l. Inst. for Road Res., S. Africa	As source document in investigating certain aspects of vehicle sizes and weights on South African highways.
20-1	(HRIS)	Many diverse agencies	The Highway Research Information Service is known to be used widely by a number of organizations in addition to state highway departments. Recognition has been given to the periodic issues of *Highway Research in Progress* as being very useful and of great value to many other government agencies.
20-2	Report 55	Illinois Div. H, Bur. R&D	A committee within the Illinois Highway Research Council, having the assignment of developing a system of establishing research priorities for the Division's program, uses the method outlined for structuring research programs.
20-3	—	California Div. of Hwys.	Although not yet published, results from the second year of research are being used as background for installing surveillance and control systems and in planning alternative methods of improving operations on the Los Angeles Area freeway system.
20-5	Synthesis 1	Conn. DOT	As a basis for current signing patterns from Maintenance.
	Synthesis 2	Lab. de Eng., Angola	Translated into Portuguese.
	Synthesis 4	California Div. of Hwys.	As a basic document in the continuing development of Division practices and procedures to cope with the bridge deck deterioration problem. Also used as a guide for those lines of research that will yield the highest return.
		U.S. DOT	In preparation of *Instructional Memorandum 40-2-70.*
		N. Mex. SHD	In revising the Department's *Bridge Construction Manual.*
	Synthesis 5	Ctr. for PW Studies and Exper. (Spain)	Translated into Spanish as an "Information Bulletin" of the Transport and Soil Mechanics Laboratory.
		Louisiana DOH	As procedural guide to emergency measures to contain and/or control scour at bridge sites.
	Synthesis 6	Conn. DOT	In project scheduling.
	Synthesis 7	92nd Cong., 1 Sess.	See Project 1-12.
		Conn. DOT	Provided justification for motorist aid call-box system.
	Synthesis 10	Conn. DOT	By Maintenance in training personnel for equipment responsibilities.
	Synthesis 11	AASHTO	As a text in Highway Management Course (conducted by the Highway Management Institute at the Univ. of Mississippi).
	Synthesis 12	Conn. DOT	As a basis for Maintenance Telecommunication System.
	Synthesis 14	Texas Hwy. Dept.	Recommended to District offices as a reference to answer skid-resistance questions from both Departmental and non-Departmental personnel.
		Conn. DOT	To provide guidelines for skid-resistance program.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	Synthesis 16	Conn. DOT	Reference source for design of CRC pavements.
	Synthesis 18	Texas HD and Tex. Div., FHWA	As background information in plan preparation and review; construction supervision and inspection; maintenance activity.
	Synthesis 24	Conn. DOT	As input into snow and ice policy.
	Synthesis 32	Conn. DOT	As backup for studded-tire legislation.
	Synthesis 37	Upper Plains States Innovation Group	Used in stabilization handbook for local governments.
	Syntheses 56 and 60	Texas SDH and Public Transp.	For review by district offices prior to Pavement Rehabilitation Conference.
	Synthesis 81	Texas SDH and Public Transp.	Text material for Corridor Management Team Conference. Participants included city and state personnel from 12 largest urban areas within Texas. Also used as text for Urban Traffic Operations and Management Seminar.
		FHWA	As source material in short courses on Organization and Management of Ridesharing.
	Syntheses 81 and 93	Univ. of Calif.—Berkeley	As reference material for course work.
20-6	Res. Dig. 11	Md. Rds. Comm.	In a case before September 1969 term, State Court of Appeals.
	Syntheses 96 and 99	FHWA	As a supplement to the training sessions on drainage and overlay designs in a "Pavement Design Training Course."
	Res. Dig. 11 and others	Colorado DOH	Used on several occasions involving condemnation cases and other legal matters. Digests noted as being extremely helpful in view of their discussions of current problems and consequent saving of legal staff time.
	Res. Results Digest 3	Sec. of Transp.	Included *in toto* in 1970 Annual Report to the Congress in respect to progress made in administration of the highway relocation assistance program as enacted under the Federal-Aid Highway Act of 1968.
	Res. Results Digests	Virginia Atty. Genl. Office	As an aid to maintaining a current awareness of legal research of an original nature, as a basis for further research by personnel of the Office, and as a point of departure for reviews of settled law.
	Res. Dig. 25	U. Wis., Dept. Eng.	As a text in short course on Urban Transportation Planning.
20-7	Legal Research Digests	American Samoa Government	To resolve issues similar to those found elsewhere in the United States of America
	—	92nd Congress, 1st Sess.	Task 4, "Laternal Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relating to Available Pavement Skid-Resistant Measures." See Project 1-12.
	Report 157	Conn. DOT	In developing the scrap tire attenuation system.
	Res. Dig. 98	FHWA	To analyze Oklahoma DOT structure upgrading program.
	Agency final report (Task 8)	New York DOT	As primary source of information on energy used in construction and maintenance of transportation facilities for estimation of energy savings by Transportation System Management (TSM) actions. TSM actions are estimated to save 37.1 million gal of gasoline in the State of N.Y. during the 1978 calendar year.
		FHWA	As the primary source document for preparing the Workshop Notes for Energy Requirements for Transportation Systems.
	Agency final report (Task 12)	AASHTO	Published by AASHTO as *Guidelines on Citizen Participation in Transportation Planning.*
	Agency final report (Task 16)	North Central Council of Governments	As an aid in the validation of a survey regarding hazardous materials shipments.
	Agency final report (Task 18)	AASHTO	Published by AASHTO in 1983 as the 13th Edition of the *Standard Specifications for Highway Bridges.*
	AASHTO Guide for Design of Pavement Structures (Task 24)	States, Counties, Cities, Consultants West Virginia University	In addition to copies distributed free to AASHTO members, more than 29,000 copies of the document have been purchased from AASHTO by the various users. Primary basis for development of pavement design manual for West Virginia Department of Highways.
	AASHTO Software Program DNPS 86/PC™ (Task 28)	States, Counties, Cities, Consultants	This personal computer program for new pavement design is based on the *AASHTO Guide for Design of Pavement Structures* and greatly simplifies implementation of the Guide. Under a licensing agreement, copies of the program have been sold by AASHTO to potential users.
	Agency final report (Task 32)	AASHTO	Adopted by the Subcommittee on Bridges and Structures as a Guide Specification in 1988.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *(Continued)*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	AASHTO Guidelines for Pavement Management Systems (Task 38)	AASHTO	Adopted and published by AASHTO, July 1990
20-12	Agency report	FHWA	In preparation of handbook on "Air Pollution Control for Construction and Maintenance."
20-13	Report 193	Metro. Expy. Public Corp. Tokyo, Japan	Translated into Japanese and distributed within the Corporation.
20-15	Report 218	Florida Dept. of Environ. Regs.	To write rules related to wetland protection.
20-16	Report 198	AASHTO	Findings used in testimony before U.S. Senate.
22-2	Res. Results Dig. 84, 102, 124	State highway agencies	Breakaway cable terminal (BCT) installed as a guardrail end treatment in at least 40 states since 1973.
		Federal Aviation Administration	To install breakaway cable terminals as part of a demonstration project on the Dulles Airport Access Highway.
	Report 153	AASHTO	Referenced in Section 1.1.9A(2), Loadings and Geometrics, of the 1975 "Interim Bridge Specifications."
	Res. Results Dig. 84, 102	Australian state hwy. agencies	Breakaway cable terminal (BCT) installed as a guardrail and treatment in at least two Australian states.
22-2(4)	Report 230	State hwy. agencies, FHWA, and full-scale, crash-testing agencies	As the guide for developing and evaluating highway safety hardware.
		Spanish hwy. engineering firm	Energy Absorption Systems Inc. (USA) working cooperatively with a Spanish firm, Bionda, S.A., translated the report into Spanish in metric units and used for selecting highway safety appurtenances for installation on highways in Spain.
22-4	Report 289	FHWA/AASHTO	Crash test results used in updating the AASHTO Barrier Guide and by individual states in selecting barrier designs.
25-1	Agency draft final report	U.S. Army Corps of Engineers Waterways Experiment Station	As a resource document.

TABLE 5

PUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
● 1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
● 2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
● 3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
● 4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
● 5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 + p., $2.00
● 6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p., $3.20
● 7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80.
● 8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00
● 9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60
● 10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80
● 11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
● 12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
● 13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
● 14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
● 15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
● 16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
● 17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $6.00
● 18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
● 19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20
● 20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
● 21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
● 22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
● 23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
● 24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
● 25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
● 26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
● 27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00
● 28	Surveillance Methods and Ways and Means Communicating with Drivers (Proj. 3-2), 66 p., $2.60
● 29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00
● 30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60
● 31	A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $2.00
● 32	Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., $5.00
● 33	Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $3.60
● 34	Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., $5.00
● 35	Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., $5.00
● 36	Highway Guardrails—A Review of Current Practice (Proj. 15-1), 33 p., $1.60
● 37	Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), 80 p., $3.60
● 38	Evaluation of Pavement Joint and Crack Sealing Materials and Practices (Proj. 9-3), 40 p., $2.00
● 39	Factors Involved in the Design of Asphaltic Pavement Surfaces (Proj. 1-8), 112 p., $5.00
● 40	Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., $2.00
● 41	Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., $3.60
● 42	Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., $5.60
● 43	Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., $2.00
● 44	Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $1.40
● 45	Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40
● 46	Effects of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $4.60
● 47	Accident Rates as Related to Design Elements of Rural Highways (Proj. 2-3), 173 p., $6.40
● 48	Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20
● 49	National Survey of Transportation Attitudes and Behavior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20
● 50	Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $5.20
● 51	Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00
● 52	Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., $3.80

* Highway Research Board Special Report 80.

NOTE: Out-of-print publications marked with a bullet (●) are available only in microfiche form from the Transportation Research Board. See final page of this document for ordering information.

TABLE 5 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
• 53	Multiple Use of Lands Within Highway Rights-of-Way (Proj. 7-6), 68 p., $3.20
• 54	Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., $2.60
• 55	Research Needs in Highway Transportation (Proj. 20-2), 66 p., $2.80
• 56	Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., $6.40
• 57	Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., $3.20
• 58	Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., $3.60
• 59	Standard Measurements for Satellite Road Test Program (Proj. 1-6), 78 p., $3.20
• 60	Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2), 148 p., $6.00
• 61	Evaluation of Studded Tire—Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., $3.00
• 62	Urban Travel Patterns for Hospitals, Universities, Office Buildings and Capitols (Proj. 7-1), 144 p., $5.60
• 63	Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., $4.00
• 64	Motorists' Needs and Services on Interstate Highways (Proj. 7-7), 88 p., $3.60
• 65	One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., $1.40
• 66	Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., $2.80
• 67	Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), 45 p., $2.20
• 68	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 3-10), 38 p., $2.00
• 69	Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (Proj. 10-2A), 58 p., $2.80
• 70	Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., $3.00
• 71	Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., $2.80
• 72	Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., $2.20
• 73	Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5), 55 p., $2.80
• 74	Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., $2.80
• 74A	Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., $8.00
• 74B	Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., $4.00
• 75	Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., $3.60
• 76	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2), 37 p., $2.00
• 77	Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., $3.80
• 78	Highway Noise—Measurement, Simulation, and Mixed Reactions (Prof. 3-7), 78 p., $3.20
• 79	Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., $6.40
• 80	Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., $5.20
• 81	Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., $5.60
• 82	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., $4.00
• 83	Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., $2.80
• 84	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., $2.40
• 85	Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., $1.80
• 86	Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., $3.20
• 87	Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., $2.00
• 88	Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., $2.00
• 89	Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., $3.20
• 90	Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., $4.00
• 91	Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research (Proj. 16-1), 70 p., $3.20
• 92	Valuation and Condemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., $2.60
• 93	Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., $6.20
• 94	Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., $1.80
• 95	Highway Fog (Proj. 5-6), 48 p., $2.40
• 96	Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., $5.40
• 97	Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., $2.60
• 98	Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), 98 p., $5.00
• 99	Visual Requirements in Night Driving (Proj. 5-3), 38 p., $2.60
• 100	Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., $3.40
• 101	Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks (Proj. 6-9), 70 p., $3.60
• 102	Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), 114 p., $5.40
• 103	Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., $5.00
• 104	Rules of Compensability and Valuation Evidence for Highway Land Acquisition (Proj. 11-1), 77 p., $4.40
• 105	Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., $5.00
• 106	Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., $3.40
• 107	New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., $2.40
• 108	Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), 75 p., $4.00
• 109	Elastomeric Bearing Research (Proj. 12-9), 53 p., $3.00
• 110	Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., $4.40

TABLE 5 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
• 111	Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., $5.20
• 112	Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., $2.60
• 113	Optimizing Flow on Existing Street Networks (Proj. 3-14), 414 p., $15.60
• 114	Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., $2.60
• 115	Guardrail Performance and Design (Proj. 15-1(2)), 70 p., $3.60
• 116	Structural Analysis and Design of Pipe Culverts (Proj. 15-3), 155 p., $6.40
• 117	Highway Noise—A Design Guide for Highway Engineers (Proj. 3-7), 79 p., $4.60
• 118	Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), 96 p., $5.20
• 119	Control of Highway Advertising Signs—Some Legal Problems (Proj. 11-3(1)), 72 p., $3.60
• 120	Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), 90 p., $4.80
• 121	Protection of Highway Utility (Proj. 8-5), 115 p., $5.60
• 122	Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., $13.60
• 123	Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12), 239 p., $9.60
• 124	Improved Criteria for Traffic Signal Systems in Urban Networks (Proj. 3-5), 86 p., $4.80
• 125	Optimization of Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5A), 86 p., $4.40
• 126	Divergencies in Right-of-Way Valuation (Proj. 11-4), 57 p., $3.00
• 127	Snow Removal and Ice Control Techniques at Interchanges (Proj. 6-10), 90 p., $5.20
• 128	Evaluation of AASHO Interim Guides for Design of Pavement Structures (Proj. 1-11), 111 p., $5.60
• 129	Guardrail Crash Test Evaluation—New Concepts and End Designs (Proj. 15-1(2)), 89 p., $4.80
• 130	Roadway Delineation Systems (Proj. 5-7), 349 p., $14.00
• 131	Performance Budgeting System for Highway Maintenance Management (Proj. 19-2(4)), 213 p., $8.40
• 132	Relationships Between Physiographic Units and Highway Design Factors (Proj. 1-3(1)), 161 p., $7.20
• 133	Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects (Proj. 7-8), 127 p., $5.60
• 134	Damages Due to Drainage, Runoff, Blasting, and Slides (Proj. 11-1(8)), 24 p., $2.80
• 135	Promising Replacements for Conventional Aggregates for Highway Use (Proj. 4-10), 53 p., $3.60
• 136	Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds (Proj. 15-4), 85 p., $4.60
• 137	Roadside Development—Evaluation of Research (Proj. 16-2), 78 p., $4.20
• 138	Instrumentation for Measurement of Moisure—Literature Review and Recommended Research (Proj. 21-1), 60 p., $4.00
• 139	Flexible Pavement Design and Management—Systems Formulation (Proj. 1-10), 64 p., $4.40
• 140	Flexible Pavement Design and Management—Materials Characterization (Proj. 1-10), 118 p., $5.60
• 141	Changes in Legal Vehicle Weights and Dimensions—Some Economic Effects on Highways (Proj. 19-3), 184 p., $8.40
• 142	Valuation of Air Space (Proj. 11-5), 48 p., $4.00
143	Bus Use of Highways—State of the Art (Proj. 8-10), 406 p., $16.00
• 144	Highway Noise—A Field Evaluation of Traffic Noise Reduction Measures (Proj. 3-7), 80 p., $4.40
• 145	Improving Traffic Operations and Safety at Exit Gore Areas (Proj. 3-17), 120 p., $6.00
• 146	Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis (Proj. 8-9), 68 p., $4.00
147	Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments (Proj. 12-7), 85 p., $4.80
• 148	Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach (Proj. 20-7), 64 p., $4.00
149	Bridge Rail Design—Factors, Trends, and Guidelines (Proj. 12-8), 49 p., $4.00
• 150	Effect of Curb Geometry and Location on Vehicle Behavior (Proj. 20-7), 88 p., $4.80
• 151	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques (Proj. 1-12(2)), 100 p., $6.00
• 152	Warrants for Highway Lighting (Proj. 5-8), 117 p., $6.40
153	Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances (Proj. 22-2), 19 p., $3.20
• 154	Determining Pavement Skid Resistance Requirements at Intersections and Braking Sites (Proj. 1-12), 64 p., $4.40
• 155	Bus Use of Highways—Planning and Design Guidelines (Proj. 8-10), 161 p., $7.60
• 156	Transportation Decision-Making—A Guide to Social and Environmental Considerations (Proj. 8-8(3)), 135 p., $7.20
157	Crash Cushions of Waste Materials (Proj. 20-7), 73 p., $4.80
• 158	Selection of Safe Roadside Cross Sections (Proj. 20-7), 57 p., $4.40
159	Weaving Areas—Design and Analysis (Proj. 3-15), 119 p., $6.40
• 160	Flexible Pavement Design and Management—Systems Approach Implementation (Proj. 1-10A), 53 p., $4.00
• 161	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities (Proj. 14-2), 55 p., $4.40
162	Methods for Evaluating Highway Safety Improvements (Proj. 17-2A), 150 p., $7.40
163	Design of Bent Caps for Concrete Box-Girder Bridges (Proj. 12-10), 124 p., $6.80
164	Fatigue Strength of High-Yield Reinforcing Bars (Proj. 4-7), 90 p., $5.60
165	Waterproof Membranes for Protection of Concrete Bridge Decks—Laboratory Phase (Proj. 12-11), 70 p., $4.80
166	Waste Materials as Potential Replacements for Highway Aggregates (Proj. 4-10A), 94 p., $5.60
167	Transportation Planning for Small Urban Areas (Proj. 8-7A), 71 p., $4.80

TABLE 5 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
168	Rapid Measurement of Concrete Pavement Thickness and Reinforcement Location—Field Evaluation of Nondestructive Systems (Proj. 10-8), 63 p., $4.80
169	Peak-Period Traffic Congestion—Options for Current Programs (Proj. 7-10), 65 p., $4.80
• 170	Effects of Deicing Salts on Plant Biota and Soils—Experimental Phase (Proj. 16-1). 88 p., $5.60
171	Highway Fog—Visibility Measures and Guidance Systems (Proj. 5-6A), 40 p., $4.00
• 172	Density Standards for Field Compaction of Granular Bases and Subbases (Proj. 4-8(2)), 73 p., $4.80
173	Highway Noise—Generation and Control (Proj. 3-7), 174 p., $8.00
174	Highway Noise—A Design Guide for Prediction and Control (Proj. 3-7), 193 p., $9.60
175	Freeway Lane Drops (Proj. 3-16), 72 p., $4.80
176	Studded Tires and Highway Safety—Feasibility of Determining Indirect Effects (Proj. 1-13(2)), 42 p., $4.00
177	Freight Data Requirements for Statewide Transportation Systems Planning—Research Report (Proj. 8-17), 196 p., $8.80
178	Freight Data Requirements for Statewide Transportation Systems Planning—User's Manual (Proj. 8-17), 155 p., $7.40
179	Evaluating Options in Statewide Transportation Planning/Programming—Issues, Techniques, and Their Relationships (Proj. 8-18), 91 p., $5.60
• 180	Cathodic Protection for Reinforced Concrete Bridge Decks—Laboratory Phase (Proj. 12-13), 135 p., $7.00
181	Subcritical Crack Growth and Fracture of Bridge Steels (Proj. 12-14), 82 p., $5.60
182	Economic Evaluation of Ice and Frost on Bridge Decks (Proj. 6-11), 73 p., $4.80
183	Studded Tires and Highway Safety—An Accident Analysis (Proj. 1-13), 70 p., $4.80
• 184	Influence of Combined Highway Grade and Horizontal Alignment on Skidding (Proj. 1-14), 33 p., $3.20
185	Grade Effects on Traffic Flow Stability and Capacity (Proj. 3-19), 110 p., $6.40
• 186	Travel Estimation Procedures for Quick Response to Urban Policy Issues (Proj. 8-12A), 70 p., $5.60
187	Quick-Response Urban Travel Estimation Techniques and Transferable Parameters—User's Guide (Proj. 8-12A), 229 p., $10.20
188	Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings (Proj. 12-12), 113 p., $6.40
• 189	Quantifying the Benefits of Separating Pedestrians and Vehicles (Proj. 20-10), 127 p., $7.00
190	Use of Polymers in Highway Concrete (Proj. 18-2), 77 p., $5.60
• 191	Effect of Air Pollution Regulations on Highway Construction and Maintenance (Proj. 20-12), 81 p., $7.00
192	Predicting Moisture-Induced Damage to Asphaltic Concrete (Proj. 4-8(3)), 46 p., $5.20
193	Beneficial Effects Associated with Freeway Construction—Environmental, Social, and Economic (Proj. 20-13), 110 p., $7.80
194	Traffic Control in Oversaturated Street Networks (Proj. 3-18(2)), 152 p., $9.60
195	Minimizing Premature Cracking in Asphaltic Concrete Pavement (Proj. 9-4), 51 p., $6.00
196	Reconditioning Heavy-Duty Freeways in Urban Areas (Proj. 14-4), 60 p., $6.40
197	Cost and Safety Effectiveness of Highway Design Elements (Proj. 3-25), 237 p., $10.60
198	State Laws and Regulations on Truck Size and Weight (Proj. 20-16), 117 p., $7.20
199	Evaluating Options in Statewide Transportation Planning/Programming—Techniques and Applications (Proj. 8-18), 190 p., $9.00
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201	Acceptance Criteria for Electroslag Weldments in Bridges (Proj. 10-10), 44 p., $5.20
• 202	Improved Pavement-Shoulder Joint Design (Proj. 14-3), 103 p., $7.20
• 203	Safety at Narrow Bridge Sites (Proj. 20-7, Task 7), 63 p., $6.00
204	Bridge Deck Joint-Sealing Systems—Evaluation and Performance Specification (Proj. 10-11), 46 p., $5.60
205	Implementing Packages of Congestion-Reducing Techniques—Strategies for Dealing with Institutional Problems of Cooperative Programs (Proj. 7-10(2)), 128 p., $7.60
206	Detection and Repair of Fatigue Damage in Welded Highway Bridges (Proj. 12-15 & 12-15(2)), 85 p., $6.80
• 207	Upgrading of Low-Quality Aggregates for PCC and Bituminous Pavements (Proj. 4-12), 91 p., $7.20
208	Market Opportunity Analysis for Short-Range Public Transportation Planning—Procedures for Evaluating Alternative Service Concepts (Proj. 8-16), 80 p., $6.80
209	Market Opportunity Analysis for Short-Range Public Transportation Planning—Transportation Services for the Transportation Disadvantaged (Proj. 8-16), 52 p., $6.00
210	Market Opportunity Analysis for Short-Range Public Transportation Planning—Economic, Energy, and Environmental Impacts (Proj. 8-16), 45 p., $6.00
211	Market Opportunity Analysis for Short-Range Public Transportation Planning—Goals and Policy Development, Institutional Constraints, and Alternative Organizational Arrangements (Proj. 8-16), 161 p., $9.20
• 212	Market Opportunity Analysis for Short-Range Public Transportation Planning—Method and Demonstration (Proj. 8-16), 132 p., $10.00
—*	Freeway Traffic Management (Proj. 20-3D), 68 p., $4.00
213	Bayesian Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress (Proj. 9-4A), 52 p., $6.00
• 214	Design and Traffic Control Guidelines for Low-Volume Rural Roads (Proj. 20-7, Task 13), 41 p., $5.60
• 215	Pavement Management System Development (Proj. 20-7, Task 15), 32 p., $5.20
216	The No-Action Alternative—Research Report (Proj. 8-11), 72 p., $6.80
217	The No-Action Alternative—Impact Assessment Guidelines (Proj. 8-11), 174 p., $9.60
• 218A	Ecological Effects of Highway Fills on Wetlands—Research Report (Proj. 20-15), 34 p., $5.20
• 218B	Ecological Effects of Highway Fills on Wetlands—User's Manual (Proj. 20-15), 99 p., $7.20

* Special publication.

TABLE 5 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
• 219	Application of Traffic Conflict Analyses at Intersections (Proj. 17-3), 109 p., $7.60
220	Erosion Control During Highway Construction—Research Report (Proj. 16-3), 30 p., $5.60
221	Erosion Control During Highway Construction—Manual on Principles and Practices (Proj. 16-3), 108 p., $14.40
222	Bridges on Secondary Highways and Local Roads—Rehabilitation and Replacement (Proj. 12-20), 132 p., $9.20
• 223	Maintenance Levels-of-Service Guidelines (Proj. 14-5), 118 p., $8.80
224	Guidelines for Recycling Pavement Materials (Proj. 1-17), 137 p., $9.20
225	Plastic Pipe for Subsurface Drainage of Transportation Facilities (Proj. 4-11), 153 p., $9.60
226	Damage Evaluation and Repair Methods for Prestressed Concrete Bridge Members (Proj. 12-21), 66 p., $7.20
227	Fatigue Behavior of Full-Scale Welded Bridge Attachments (Proj. 12-15(3)), 47 p., $6.40
228	Calibration of Response-Type Road Roughness Measuring Systems (Proj. 1-18), 81 p., $7.60
229	Methods for Analyzing Fuel Supply Limitation on Passenger Travel (Proj. 8-23), 132 p., $9.20
230	Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances (Proj. 22-2(4)), 42 p., $6.00
231	State Transportation Finance Within the Context of Energy Constraints (Proj. 8-22), 86 p., $7.60
232	Guidelines for Selection of Ramp Control Systems (Proj. 3-22A), 108 p., $8.40
233	Selecting Traffic Signal Control at Individual Intersections (Proj. 3-27), 133 p., $9.20
234	Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks—Field Evaluation (Proj. 12-13A), 64 p., $6.80
235	Effectiveness of Changeable Message Displays in Advance of High-Speed Freeway Lane Closures (Proj. 3-21(2)), 49 p., $7.00
236	Evaluation of Traffic Controls for Highway Work Zones (Proj. 17-4, 17-4(2)), 189 p., $12.00
• 237	Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques (Proj. 10-14), 40 p., $6.80
238	Estimating Exceedances and Design Values from Data Collected by Urban Ozone Monitoring Networks (Proj. 20-14A), 121 p., $9.60
239	Multiple-Service-Level Highway Bridge Railing Selection Procedures (Proj. 22-2(3)), 161 p., $10.40
240	A Manual to Determine Benefits of Separating Pedestrians and Vehicles (Proj. 20-10(2)), 56 p., $7.20
241	Guidelines for Using Vanpools and Carpools as a TSM Technique (Proj. 8-21), 154 p., $10.40
242	Ultrasonic Measurement of Weld Flaw Size (Proj. 10-13), 76 p., $8.00
243	Rehabilitation and Replacement of Bridges on Secondary Highways and Local Roads (Proj. 12-20), 46 p., $6.80
244	Concrete Sealers for Protection of Bridge Structures (Proj. 12-19A), 138 p., $10.00
245	Methodology for Evaluating Highway Air Pollution Dispersion Models (Proj. 20-18), 85 p., $8.40
• 246	Predicting Moisture-Induced Damage to Asphaltic Concrete—Field Evaluation (Proj. 4-8(3)) 50 p., $7.20
247	Effectiveness of Clear Recovery Zones (Proj. 17-5) 68 p., $7.20
248	Elastomeric Bearings Design, Construction, and Materials (Proj. 10-20), 82 p., $8.40
249	Peak-Hour Traffic Signal Warrant (Proj. 3-20A), 71 p., $7.60
250	New Approaches to Understanding Travel Behavior (Proj. 8-14A), 142 p., $10.00
251	Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline (Proj. 10-16), 80 p., $8.40
252	Adding Dust Collector Fines to Asphalt Paving Mixtures (Proj. 10-19), 90 p., $8.40
253	Application of Disaggregate Travel Demand Models (Proj. 8-13(2)), 207 p., $12.40
254	Shoulder Geometrics and Use Guidelines (Proj. 1-22), 71 p., $7.60
255	Highway Traffic Data for Urbanized Area Project Planning and Design (Proj. 8-26), 191 p., $11.60
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257	Long-Term Rehabilitation of Salt-Contaminated Bridge Decks (Proj. 18-2(3)), 32 p., $6.40
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262	Planning Transportation Services for Handicapped Persons—User's Guide (Proj. 8-27), 74 p., $8.00
263	Simplified Procedures for Evaluating Low-Cost TSM Projects—User's Manual (Proj. 7-11), 209 p., $12.80
264	Guidelines for the Management of Highway Runoff on Wetlands (Proj. 25-1), 166 p., $10.80
265	Removal of Lead-Based Bridge Paints (Proj. 10-23), 72 p., $8.00
266	Forecasting Inputs to Transportation Planning (Proj. 8-24), 117 p., $9.60
267	Steel Bridge Members Under Variable Amplitude Long Life Fatigue Loading (Proj. 12-15(4)), 26 p., $6.40
268	Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance (Proj. 1-20), 62 p., $7.60
269	Paving with Asphalt Cements Produced in the 1980's (Proj. 1-20), 28 p., $6.40
270	Parameters Affecting Stopping Sight Distance (Proj. 15-8), 169 p., $11.20
271	Guidelines for Evaluation and Repair of Damaged Steel Bridge Members (Proj. 12-17A), 64 p., $7.60
272	Performance of Weathering Steel in Bridges (Proj. 10-22), 164 p., $12.00
273	Manual for the Selection of Optimal Maintenance Levels of Service (Proj. 14-5(2)), 81 p., $9.20
274	Use of Antistripping Additives in Asphaltic Concrete Mixtures—Laboratory Phase (Proj. 10-17), 50 p., $7.60
275	Pavement Roughness and Rideability (Proj. 1-23), 69 p., $8.80

TABLE 5 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
276	Thermal Effects in Concrete Bridge Superstructures (Proj. 12-22), 99 p., $9.60
277	Portland Cement Concrete Pavement Evaluation System (COPES) (Proj. 1-19), 175 p., $12.80
278	Cathodic Protection of Concrete Bridge Substructures (Proj. 12-19B), 60 p., $8.40
279	Intersection Channelization Design Guide (Proj. 3-30), 153 p., $25.00
280	Guidelines for Evaluation and Repair of Damaged Prestressed Concrete Bridge Members (Proj. 12-21), 84 p., $9.20
281	Joint Repair Methods for Portland Cement Concrete Pavements—Design and Construction Guidelines (Proj. 1-21), 83 p., $9.20
282	Multilane Design Alternatives for Improving Suburban Highways (Proj. 2-13), 71 p., $8.50
283	Training Aid for Applying NCHRP Report 263—Simplified Procedures for Evaluating Low-Cost TSM Projects (Proj. 7-11A), 34 p., $7.20
284	Evaluation of Procedures Used to Measure Cement and Water Content in Fresh Concrete (Proj. 10-25), 76 p., $9.20
285	Evaluating Alternative Maintenance Strategies (Proj. 14-6), 86 p., $10.40
286	Evaluation of Fatigue Tests and Design Criteria on Welded Details (Proj. 12-15(5)), 66 p., $8.40
287	Load Distribution and Connection Design for Precast Stemmed Multibeam Bridge Superstructures (Proj. 12-24), 137 p., $11.80
288	Evaluating Grade-Separated Rail-Highway Crossing Alternatives (Proj. 3-31), 87 p., $10.80
289	Performance of Longitudinal Traffic Barriers (Proj. 22-4), 169 p., $13.20
290	Reinforcement of Earth Slopes and Embankments (Proj. 24-2), 323 p., $40.00
291	Development of Pavement Structural Subsystems (Proj. 1-10B), 59 p., $8.80
292	Strength Evaluation of Existing Reinforced Concrete Bridges (Proj. 10-15), 133 p., $14.00
293	Methods of Strengthening Existing Highway Bridges (Proj. 12-28(4)), 114 p., $12.00
294A	Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas—Research Report (Proj. 20-19), 92 p., $10.40
294B	Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas—State-of-the-Art Report (Proj. 20-19), 165 p., $12.40
295	Automated Field Survey Data Collection System (Proj. 20-21), 107 p., $13.20
296	Durability of In-Place Concrete Containing High-Range Water-Reducing Admixtures (Proj. 10-32), 63 p., $10.40
297	Evaluation of Bridge Deck Protective Strategies (Proj. 12-32), 80 p., $12.00
298	Performance of Elastomeric Bearings (Proj. 10-20), 100 p., $12.00
299	Fatigue Evaluation Procedures for Steel Bridges (Proj. 12-28(3)), 94 p., $11.20
300	Bridge Management Systems (Proj. 12-28(2)), 74 p., $10.40
301	Load Capacity Evaluation of Existing Bridges (Proj. 12-28(1)), 104 p., $11.60
302	Fatigue and Fracture Evaluation for Rating Riveted Bridges (Proj. 12-25), 86 p., $11.20
303	Feasibility of a National Heavy Vehicle Monitoring System (Proj. 3-34), 68 p., $10.00
304	Determining Deteriorated Areas in Portland Cement Concrete Pavements Using Radar and Video Imaging (Proj. 10-28), 107 p., $14.00
305	Environmental Monitoring and Evaluation of Calcium Magnesium Acetate (CMA) (Proj. 4-17), 160 p., $13.60
306	Correlation of Bridge Load Capacity Estimates with Test Data (Proj. 12-28(8)), 75 p., $11.20
307	Public and Private Partnerships for Financing Highway Improvements (Proj. 2-14), 83 p., $11.20
308	Pavement Roughness and Rideability—Field Evaluation (Proj. 1-23(2)), 48 p., $9.00
309	Protection of Pipelines Through Highway Roadbeds (Proj. 15-9), 21 p., $8.00
310	Dealing with Hazardous Waste Sites—A Compendium for Highway Agencies (Proj. 20-22), 107 p., $12.00
311	Predicting Stop-and-Go Traffic Noise Levels (Proj. 25-2), 97 p., $11.00
312	Condition Surveys of Concrete Bridge Components—User's Manual (Proj. 12-28(5)), 84 p., $11.00
313	Corrosion Protection of Prestressing Systems in Concrete Bridges (Proj. 4-15) 25 p., $8.00
314	Guidelines for the Use of Weathering Steel in Bridges (Proj. 10-22), 98 p., $16.00
315	Potential Benefits of Geosynthetics in Flexible Pavement Systems (Proj. 10-33), 56 p., $9.00
316	Laboratory Evaluation of Piles Installed with Vibratory Drivers (Proj. 24-3), 51 p., $9.00
317	Transient Protection, Grounding, and Shielding of Electronic Traffic Control Equipment (Proj. 10-34), 84 p., $11.00
318	Roadside Safety Design for Small Vehicles (Proj. 22-6), 70 p., $10.00
319	Recommended Guidelines for Redundancy Design and Rating of Two-Girder Steel Bridges (Proj. 12-28(10)), 142 p., $13.00
320	Guidelines for Converting STOP to YIELD Control at Intersections (Proj. 17-7), 49 p., $9.00
321	Welded Repair of Cracks in Steel Bridge Members (Proj. 12-27), 46 p., $8.00
322	Design of Precast Prestressed Bridge Girders (Proj. 12-29), 97 p., $11.00
323	Travel Characteristics at Large-Scale Suburban Activity Centers (Proj. 3-38(2)), 106 p., $11.00
324	Evaluation of Safety Roadside Rest Areas (Proj. 2-15), 129 p., $12.00
325	Low Temperature Behavior and Acceptance Criteria for Elastomeric Bridge Bearings (Proj. 10-20), 69 p. $9.00
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328	Forecasting the Basic Inputs to Transportation Planning at the Zonal Level (Proj. 8-24A) 55 p., $9.00
329	Using Market Research to Improve Management of Transportation Systems (Proj. 20-24(1)), 75 p., $10.00

TABLE 5 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
330	Effective Utilization of Street Width on Urban Arterials (Proj. 3-38(5)), 49 p., $9.00
331	Strategic Planning and Management Guidelines for Transportation Agencies (Proj. 8-28), 49 p., $9.00
332	Framework for Development of Performance-Related Specifications for Hot-Mix Asphaltic Concrete (Proj. 10-26A), 118 p., $12.00
333	Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges (Proj. 12-28(7)), 140 p., $30.00
334	Improvements in Data Acquisition Technology for Maintenance Management Systems (Proj. 14-10), 51 p., $9.00
335	Acceptance Criteria for Steel Bridge Welds (Proj. 10-31), 26 p., $7.00
336	Distortion-Induced Fatigue Cracking in Steel Bridges (Proj. 12-28(6)), 43 p., $10.00
337	Service Vehicle Lighting and Traffic Control Systems for Short Term and Moving Operations (Proj. 17-6A), 56 p., $10.00
338	Asphalt-Aggregate Mixture Analysis System—AAMAS (Proj. 9-6(1)), 185 p., $20.00
339	Effects of the Quality of Traffic Signal Progression on Delay (Proj. 3-38C), 100 p., $11.00
340	Assessment of Advanced Technologies for Relieving Urban Traffic Congestion (Proj. 3-38(1)), 98 pp. $11.00
341	Bond and Insurance Coverages for Highway Construction Contractors (Proj. 20-26), 47 p., $8.00
342	Primer on Transportation, Productivity and Economic Development (Proj. 2-17(1)), 127 p., $12.00
343	Manuals for the Design of Bridge Foundations: Shallow Foundations, Driven Piles, Retaining Walls and Abutments, Drilled Shafts, Estimating Tolerable Movements, Load Factor Design Specifications and Commentary (Proj. 24-4), 308 p., $45.00
344	Maintenance Contracting (Proj. 14-9(3)), 111 p. $9.00
345	Single Point Urban Interchange Design and Operations Analysis (Proj. 3-40), 101 p., $12.00
346	Implementation Strategies for Sign Retroreflectivity Standards (Proj. 5-11), 44 p., $9.00
347	Civil Engineering Careers: Awareness, Retention, and Curriculum (Proj. 20-24(3)), 118 p., $12.00
348	Access Management Guidelines for Activity Centers (Proj. 3-38(7)), 112 p., $12.00
349	Maintenance Considerations in Highway Design (Proj. 14-9(2)), 82 p., $10.00
350	Recommended Procedures for the Safety Performance Evaluation of Highway Features (Proj. 22-7), 132 pp., $13.00
351	Hazardous Wastes in Highway Rights-of Way (Proj. 20-28), 114 p., $28.00
352	Inelastic Rating Procedures for Steel Beam and Girder Bridges (Proj. 12-28(12)), 112 p., $13.00
353	Effects of Heavy-Vehicle Characteristics on Pavement Response and Performance (Proj. 1-25(1)), 126 p., $15.00
354	Resistance of Welded Details Under Variable Amplitude Long-Life Fatigue Loading (Proj. 12-15(5)), 38 p., $10.00
355	Notch Toughness Variability in Bridge Steel Plates (Proj. 12-31), 66 p., $21.00
356	Anchorage Zone Reinforcement for Post-Tensioned Concrete Girders (Proj. 10-29), 214 p., $41.00
357	Measuring State Transportation Program Performance (Proj. 20-24(6)A), 102 p., $24.00
358	Traffic Barriers and Control Treatments for Restricted Work Zones (Proj. 17-8), (In Press)
359	Adaptation of Geographic Information Systems for Transportation (Proj. 20-27), 80 p., $24.00
360	Professional Development of Maintenance Engineers and Managers (Proj. 14-9(6)), (In preparation)
361	Field Demonstrations of Advanced Data Acquisition Technology for Maintenance Management (Proj. 14-10), 122 p., $25.00

TABLE 5 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PROJECT, PAGES, PRICE
1	Traffic Control for Freeway Maintenance (Proj. 20-5, Topic 1), 47 p., $2.20
● 2	Bridge Approach Design and Construction Practices (Proj. 20-5, Topic 2), 30 p., $2.00
● 3	Traffic-Safe and Hydraulically Efficient Drainage Practice (Proj. 20-5, Topic 4), 38 p., $2.20
● 4	Concrete Bridge Deck Durability (Proj. 20-5, Topic 3), 28 p., $2.20
● 5	Scour at Bridge Waterways (Proj. 20-5, Topic 5), 37 p., $2.40
● 6	Principles of Project Scheduling and Monitoring (Proj. 20-5, Topic 6), 43 p., $2.40
7	Motorist Aid Systems (Proj. 20-5, Topic 3-01), 28 p., $2.40
● 8	Construction of Embankments (Proj. 20-5, Topic 9), 38 p., $2.40
● 9	Pavement Rehabilitation—Materials and Techniques (Proj. 20-5, Topic 8), 41 p., $2.80
● 10	Recruiting, Training, and Retaining Maintenance and Equipment Personnel (Proj. 20-5, Topic 10), 35 p., $280
● 11	Development of Management Capability (Proj. 20-5, Topic 12), 50 p., $3.20
12	Telecommunications Systems for Highway Administration and Operations (Proj. 20-5, Topic 3-03), 29 p., $2.80
13	Radio Spectrum Frequency Management (Proj. 20-5, Topic 3-03), 32 p., $2.80
● 14	Skid Resistance (Proj. 20-5, Topic 7), 66 p., $4.00
● 15	Statewide Transportation Planning—Needs and Requirements (Proj. 20-5, Topic 3-02), 41 p., $3.60
16	Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 3-08), 23 p., $2.80
17	Pavement Traffic Marking—Materials and Application Affecting Serviceability (Proj. 20-5, Topic 3-05), 44 p., $3.60
● 18	Erosion Control on Highway Construction (Proj. 20-5, Topic 4-01), 52 p., $4.00
● 19	Design, Construction, and Maintenance of PCC Pavement Joints (Proj. 20-5, Topic 3-04), 40 p., $3.60
20	Rest Areas (Proj. 20-5, Topic 4-04), 38 p., $3.60
21	Highway Location Reference Methods (Proj. 20-5, Topic 4-06), 30 p., $3.20
● 22	Maintenance Management of Traffic Signal Equipment and Systems (Proj. 20-5, Topic 4-03), 41 p., $4.00
23	Getting Research Findings into Practice (Proj. 20-5, Topic 11), 24 p., $3.20
● 24	Minimizing Deicing Chemical Use (Proj. 20-5, Topic 4-02), 58 p., $4.00
25	Reconditioning High-Volume Freeways in Urban Areas (Proj. 20-5, Topic 5-01), 56 p., $4.00
● 26	Roadway Design in Seasonal Frost Areas (Proj. 20-5, Topic 3-07), 104 p., $6.00
● 27	PCC Pavements for Low-Volume Roads and City Streets (Proj. 20-5, Topic 5-06), 31 p., $3.60
28	Partial-Lane Pavement Widening (Proj. 20-5, Topic 5-05), 30 p., $3.20
29	Treatment of Soft Foundations for Highway Embankments (Proj. 20-5, Topic 4-09), 25 p., $3.20
● 30	Bituminous Emulsions for Highway Pavements (Proj. 20-5, Topic 6-10), 76 p., $4.80
31	Highway Tunnel Operations (Proj. 20-5, Topic 5-08), 29 p., $3.20
32	Effects of Studded Tires (Proj. 20-5, Topic 5-13), 46 p., $4.00
33	Acquisition and Use of Geotechnical Information (Proj. 20-5, Topic 5-03), 40 p., $4.00
● 34	Policies for Accommodation of Utilities on Highway Rights-of-Way (Proj. 20-5, Topic 6-03), 22 p., $3.20
35	Design and Control of Freeway Off-Ramp Terminals (Proj. 20-5, Topic 5-02), 61 p., $4.40
36	Instrumentation and Equipment for Testing Highway Materials, Products, and Performance (Proj. 20-5, Topic 6-01), 70 p., $4.80
● 37	Lime-Fly Ash-Stabilized Bases and Subbases (Proj. 20-5, Topic 6-06), 66 p., $4.80
38	Statistically Oriented End-Result Specifications (Proj. 20-5, Topic 6-02), 40 p., $4.00
● 39	Transportation Requirements for the Handicapped, Elderly, and Economically Disadvantaged (Proj. 20-5, Topic 6-07), 54 p., $4.40
40	Staffing and Management for Social, Economic, and Environmental Impact Assessments (Proj. 20-5, Topic 7-02), 43 p., $4.00
● 41	Bridge Bearings (Proj. 20-5, Topic 6-09), 62 p., $4.80
42	Design of Pile Foundations (Proj. 20-5, Topic 5-04), 68 p., $4.80
43	Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation (Proj. 20-5, Topic 7-05), 57 p., $4.80
44	Consolidation of Concrete for Pavements, Bridge Decks, and Overlays (Proj. 20-5, Topic 7-01), 61 p., $4.80
● 45	Rapid-Setting Materials for patching of Concrete (Proj. 20-5, Topic 6-05), 13 p., $2.40
46	Recording and Reporting Methods for Highway Maintenance Expenditures (Proj. 20-5, Topic 7-04), 35 p., $3.60
47	Effect of Weather on Highway Construction (Proj. 20-5, Topic 5-07), 29 p., $3.20
48	Priority Programming and Project Selection (Proj. 20-5, Topic 7-07), 31 p., $3.20
49	Open-Graded Friction Courses for Highways (Proj. 20-5, Topic 8-09), 50 p., $4.00
● 50	Durability of Drainage Pipe (Proj. 20-5, Topic 5-09), 37 p., $3.60
51	Construction Contract Staffing (Proj. 20-5, Topic 8-02), 62 p., $6.00
52	Management and Selection Systems for Highway Maintenance equipment (Proj. 20-5, Topic 8-08), 17 p., $4.40
53	Precast Concrete Elements for Transportation Facilities (Proj. 20-5, Topic 8-05), 48 p., $5.60
54	Recycling Materials for Highways (Proj. 20-5, Topic 8-01), 53 p., $5.60
55	Storage and Retrieval Systems for Highway and Transportation Data (Proj. 20-5, Topic 8-06), 30 p., $4.80
56	Joint-Related Distress in PCC Pavement—Cause, Prevention and Rehabilitation (Proj. 20-5, Topic 7-06), 36 p., $5.20
● 57	Durability of Concrete Bridge Decks (Proj. 20-5, Topic 9-01), 61 p., $6.00
58	Consequences of Deferred Maintenance (Proj. 20-5, Topic 10-01), 24 p., $4.40
59	Relationship of Asphalt Cement Properties to Pavement Durability (Proj. 20-5, Topic 8-11), 43 p., $5.60

TABLE 5 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PROJECT, PAGES, PRICE
60	Failure and Repair of Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 9-08), 42 p., $5.60
61	Changeable Message Signs (Proj. 20-5, Topic 9-03), 37 p., $5.60
62	State Resources for Financing Transportation Programs (Proj. 20-5, Topic 9-09), 34 p., $5.20
63	Design and Use of Highway Shoulders (Proj. 20-5, Topic 8-03), 26 p., $4.80
64	Bituminous Patching Mixtures (Proj. 20-5, Topic 8-12), 26 p., $4.80
65	Quality Assurance (Proj. 20-5, Topic 9-05), 42 p., $5.60
66	Glare Screen Guidelines (Proj. 20-5, Topic 9-11), 17 p., $4.40
67	Bridge Drainage Systems (Proj. 20-5, Topic 10-06), 44 p., $5.60
68	Motor Vehicle Size and Weight Regulations, Enforcement, and Permit Operations (Proj. 20-5, Topic 10-04), 45 p., $6.00
● **69**	Bus Route and Schedule Planning Guidelines (Proj. 20-5, Topic 7-09), 99 p., $8.00
70	Design of Sedimentation Basins (Proj. 20-5, Topic 9-10), 54 p., $6.80
71	Direction Finding from Arterials to Destinations (Proj. 20-5, Topic 9-07), 50 p., $6.40
72	Transportation Needs Studies and Financial Constraints (Proj. 20-5, Topic 11-01), 54 p., $6.80
73	Alternative Work Schedules: Impacts on Transportation (Proj. 20-5, Topic 9-06), 54 p., $6.80
74	State Transit-Management Assistance to Local Communities (Proj. 20-5, Topic 10-11), 35 p., $6.00
75	Transit Boards—Composition, Roles, and Procedures (Proj. 20-5, Topic 11-09), 24 p., $6.20
76	Collection and Use of Pavement Condition Data (Proj. 20-5, Topic 10-05), 74 p., $8.00
77	Evaluation of Pavement Maintenance Stategies (Proj. 20-5, Topic 11-08), 56 p., $7.40
78	Value Engineering in Preconstruction and Construction (Proj. 20-5, Topic 11-02, 03), 23 p., $6.40
79	Contract Time Determination (Proj. 20-5, Topic 11-10), 45 p., $7.20
80	Formulating and Justifying Highway Maintenance Budgets (Proj. 20-5, Topic 10-03), 49 p., $7.20
81	Experiences in Transportation System Management (Proj. 20-5, Topic 11-14), 88 p., $8.40
82	Criteria for Evaluation of Truck Weight Enforcement Programs (Proj. 20-5, Topic 12-02), 74 p., $7.20
83	Bus Transit Accessibility for the Handicapped in Urban Areas (Proj. 20-5, Topic 11-13), 73 p., $7.60
84	Evaluation Criteria and Priority Setting for State Highway Programs (Proj. 20-5, Topic 12-01), 32 p. $6.40
85	Energy Involved in Construction Materials and Procedures (Proj. 20-5, Topic 12-09), 34 p., $6.40
86	Effects of Traffic-Induced Vibrations on Bridge-Deck Repairs (Proj. 20-5, Topic 10-21), 40 p., $6.80
87	Highway Noise Barriers (Proj. 20-5, Topic 12-07), 82 p., $7.20
88	Underwater Inspection and Repairs of Bridge Substructures (Proj. 20-5, Topic 10-08), 77 p., $7.60
89	Geotechnical Instrumentation for Monitoring Field Performance (Proj. 20-5, Topic 11-06), 46 p., $6.80
90	New-Product Evaluation Procedures (Proj. 20-5, Topic 12-12), 34 pp., $6.80
91	Highway Accident Analysis Systems (Proj. 20-5, Topic 12-03), 69 pp., $7.60
92	Minimizing Reflection Cracking of Pavement Overlays (Proj. 20-5, Topic 11-04), 38 pp., $6.80
93	Coordination of Transportation System Management and Land Use Management (Proj. 20-5, Topic 12-08), 38 pp. $6.80
94	Photologging (Proj. 20-5, Topic 8-10), 38 p., $6.80
95	Statewide Transportation Planning (Proj. 20-5, Topic 13-05), 54 p., $7.20
96	Pavement Subsurface Drainage Systems (Proj. 20-5, Topic 11-07), 38 p., $6.80
97	Transit Ownership/Operation Options for Small Urban and Rural Areas (Proj. 20-5, Topic 13-06), 28 p., $6.40
98	Resealing Joints and Cracks in Rigid and Flexible Pavements (Proj. 20-5, Topic 12-04), 62 p., $7.20
● **99**	Resurfacing with Portland Cement Concrete (Proj. 20-5, Topic 13-04), 90 p., $8.40
100	Managing State Highway Finance (Proj. 20-5, Topic 13-03), 23 p., $6.40
101	Historic Bridges: Criteria for Decision Making (Proj. 20-5, Topic 13-11), 84 p., $8.00
102	Material Certification and Material-Certification Effectiveness (Proj. 20-5, Topic 14-05), 24 p., $6.00
103	Risk Assessment Process for Hazardous Materials Transportation (Proj. 20-5, Topic 13-10), 36 p., $6.40
104	Criteria for Use of Asphalt Friction Surfaces (Proj. 20-5, Topic 14-08), 41 p., $6.80
105	Construction Contract Claims: Causes and Methods of Settlement (Proj. 20-5, Topic 13-01), 58 p., $7.20
106	Practical Guidelines for Minimizing Tort Liability (Proj. 20-5, Topic 14-01), 40 p., $6.80
107	Shallow Foundations for Highway Structures (Proj. 20-5, Topic 12-06), 38 p., $6.80
108	Bridge Weight Limit Posting Practice (Proj. 20-5, Topic 13-08), 30 p., $6.40
109	Highway Users of Epoxy with Concrete (Proj. 20-5, Topic 14-12), 68 p., $8.80
110	Maintenance Management Systems (Proj. 20-5, Topic 14-06), 49 p., $8.00
111	Distribution of Wheel Loads on Highway Bridges (Proj. 20-5, Topic 14-22), 21 p., $7.20
112	Cost Effectiveness of Hot-Dip Galvanizing for Exposed Steel (Proj. 20-5, Topic 15-19), 28 p., $7.20
113	Administration of Research, Development, and Implementation Activities in Highway Agencies (Proj. 20-5, Topic 14-11), 49 p., $8.00
114	Management of Traffic Signal Maintenance (Proj. 20-5, Topic 14-02), 133 p., $10.80
115	Reducing Construction Conflicts Between Highways and Utilities (Proj. 20-5, Topic 14-03), 72 p., $8.80
116	Asphalt Overlay Design Procedures (Proj. 20-5, Topic 14-04), 66 p., $8.40
117	Toll Highway Financing (Proj. 20-5, Topic 15-01), 29 p., $7.20
118	Detecting Defects and Deterioration in Highway Structures (Proj. 20-5, Topic 15-03), 52 p., $8.00
119	Prefabricated Bridge Elements and Systems (Proj. 20-5, Topic 15-10), 75 p., $8.80
120	Professional Resource Management and Forecasting (Proj. 20-5, Topic 15-08), 14 p., $6.80

TABLE 5 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PROJECT, PAGES, PRICE
121	Energy Conservation in Transportation (Proj. 20-5, Topic 14-09), 25 p., $7.20
122	Life-Cycle Cost Analysis of Pavements (Proj. 20-5, Topic 15-07), 136 p., $10.80
123	Bridge Designs to Reduce and Facilitate Maintenance Repairs (Proj. 20-5, Topic 12-11), 65 p., $8.40
124	Use of Weigh-In-Motion Systems for Data Collection and Enforcement (Proj. 20-5, Topic 16-02), 34 p., $7.60
125	Maintenance Activities Accomplished by Contract (Proj. 20-5, Topic 14-07), 42 p., $8.00
126	Equipment for Obtaining Pavement Condition and Traffic Loading Data (Proj. 20-5, Topic 15-04), 117 p., $11.20
127	Use of Fly Ash in Concrete (Proj. 20-5, Topic 16-07), 66 p., $8.40
• **128**	Methods of Identifying Hazardous Highway Elements (Proj. 20-5, Topic 15-06), 80 p., $10.00
129	Freezing and Thawing Resistance of High-Strength Concrete (Proj. 20-5, Topic 16-05), 31 p., $7.60
130	Traffic Data Collection and Analysis: Methods and Procedures (Proj. 20-5, Topic 15-11), 58 p., $8.40
131	Effects of Permit and Illegal Overloads on Pavements (Proj. 20-5, Topic 15-05), 99 p., $10.40
132	System-Wide Safety Improvements: An Approach to Safety Consistency (Proj. 20-5, Topic 17-01), 20 p., $6.80
133	Integrated Highway Information Systems (Proj. 20-5, Topic 17-02), 31 p., $7.60
134	D-Cracking of Concrete Pavements (Proj. 20-5, Topic 17-08), 33 p., $7.60
135	Pavement Management Practices (Proj. 20-5, Topic 17-10), 139 p., $12.40
136	Protective Coatings for Bridge Steel (Proj. 20-5, Topic 15-09), 107 p., $11.00
137	Negotiating and Contracting for Professional Engineering Services (Proj. 20-5, Topic 18-05), 75 p., $10.00
138	Pavement Markings Materials and Application for Extended Service Life (Proj. 20-5, Topic 18-06), 45 p., $8.00
139	Pedestrians and Traffic-Control Measures (Proj. 20-5, Topic 17-11), 75 p., $9.00
140	Durability of Prestressed Concrete Highway Structures (Proj. 20-5, Topic 15-02), 65 p., $9.00
141	Bridge Deck Joints (Proj. 20-5, Topic 16-10), 66 p., $9.00
142	Methods of Cost-Effectiveness Analysis for Highway Projects (Proj. 20-5, Topic 13-02), 22 p., $7.00
143	Uniformity Efforts in Oversize/Overweight Permits (Proj. 20-5, Topic 19-02), 79 p., $10.00
144	Breaking/Cracking and Seating Concrete Pavements (Proj. 20-5, Topic 17-09), 39 p., $8.00
145	Staffing Considerations in Construction Engineering Management (Proj. 20-5, Topic 17-13), 42 p., $8.00
146	Use of Consultants for Construction Engineering and Inspection (Proj. 20-5, Topic 18-01), 64 p., $9.00
147	Treatment of Problem Foundations for Highway Embankments (Proj. 20-5, Topic 18-04), 72 p., $9.00
148	Indicators of Quality in Maintenance (Proj. 20-5, Topic 18-12), 114 p., $11.00
149	Partnerships for Innovation: Private-Sector Contributions to Innovation in the Highway Industry (Proj. 20-5, Topic 19-23), 45 p., $8.00
150	Technology Transfer in Selected Highway Agencies (Proj. 20-5, Topic 19-08), 38 p., $8.00
151	Process for Recapitalizing Highway Transportation Systems (Proj. 20-5, Topic 19-06), 43 p., $8.00
152	Compaction of Asphalt Pavement (Proj. 20-5, Topic 19-04), 42 p. $8.00
153	Evolution and Benefits of Preventive Maintenance (Proj. 20-5, Topic 18-11), 69 p., $9.00
• **154**	Recycling of Portland Cement Concrete Pavements (Project 20-5, Topic 17-06), 46 p., $8.00
155	Sign Evaluation and Replacement Programs: Policies and Criteria for Freeways and Expressways (Proj. 20-5, Topic 19-07), 37 p., $8.00
156	Freeway Incident Management (Proj. 20-5, Topic 18-08), 23 p., $7.00
157	Maintenance Management of Street and Highway Signs (Proj. 20-5, Topic 16-03), 134 p., $12.00
158	Wet Pavement Safety Programs (Proj. 20-5, Topic 16-06), 54 p., $8.00
159	Design and Construction of Bridge Approaches (Proj. 20-5, Topic 18-03), 45 p., $8.00
160	Cold-Recycled Bituminous Concrete Using Bituminous Materials (Proj. 20-5, Topic 18-09), 105 p., $11.00
161	Computer-Aided Design and Drafting Systems (Proj. 20-5, Topic 19-01), 24 p., $7.00
162	Signing Policies, Procedures, Practices, and Fees for Logo and Tourist-Oriented Directional Signing (Proj. 20-5, Topic 20-03), 41 p., $8.00
163	Innovative Strategies for Upgrading Personnel in State Transportation Departments (Proj. 20-5, Topic 18-02), 35 p., $7.00
164	Measure to Curtail State Fuel Tax Evasion (Proj. 20-5, Topic 20-02), 14 p., $7.00
165	Transportation Telecommunications (Proj. 20-5, Topic 19-10), 92 p., $10.00
166	Traffic Signal Control Equipment: State of the Art (Proj. 20-5, Topic 20-08), 43 p., $8.00
167	Measurements, Specifications, and Achievement of Smoothness for Pavement Construction (Proj. 20-5, Topic 19-12), 34 p., $8.00
168	Contract Management Systems (Proj. 20-5, Topic 18-10), 74 p., $9.00
169	Removing Concrete from Bridges (Proj. 20-5, Topic 20-07), 42 p., $8.00
170	Managing Urban Freeway Maintenance (Proj. 20-5, Topic 16-09), 26 p., $7.00
171	Fabrics in Asphalt Overlays and Pavement Maintenance (Proj. 20-5, Topic 20-01), 72 p., $9.00
172	Signal Timing Improvement Practices (Proj. 20-5, Topic 19-03), 88 p., $11.00
173	Short-Term Maintenance Systems (Proj. 20-5, Topic 20-5), 44 p., $8.00
174	Stormwater Management for Transportation Facilities (Proj. 20-5, Topic 13-07), 82 p., $9.00
175	Moisture Damage in Asphalt Concrete (Proj. 20-5, Topic 19-09), 91 p., $10.00
176	Bridge Paint: Removal, Containment, and Disposal (Proj. 20-5, Topic 20-09), 60 p., $9.00
177	Freeway Corridor Management (Proj. 20-5, Topic 18-07), 64 p., $9.00
178	Truck Escape Ramps (Proj. 20-5, Topic 21-12), 64 p., $9.00

TABLE 5 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PROJECT, PAGES, PRICE
179	Latex-Modified Mortars and Concretes (Proj. 20-5, Topic 20-12), 59 p., $9.00
180	Performance Characteristics of Open-Graded Friction Courses (Proj. 20-5, Topic 20-01), 44 p., $8.00
181	In-Service Experience with Traffic Noise Barriers (Proj. 20-5, Topic 20-11), 61 p., $8.00
182	Performance and Operational Experience of Truck-Mounted Attenuators (Proj. 20-5, Topic 22-01), 54 p., $9.00
183	Knowledge Based Expert Systems in Transportation (Proj. 20-5, Topic 22-09), 52 p., $9.00
184	Disposal of Roadside Litter Mixtures (Proj. 20-5, Topic 22-08), 52 p., $12.00
185	Preferential Lane Treatments for High-Occupancy Vehicles (Proj. 20-5, Topic 21-02), 80 p., $10.00
186	Supplemental Advance Warning Devices (Proj. 20-5, Topic 21-09), 83 p., $19.00
187	Rapid Test Methods for Asphalt Concrete and Portland Cement Concrete (Proj. 20-5, Topic 23-02), 47 p., $10.00
189	Pavement Structural Design Practices (Proj. 20-5, Topic 21-13), 45 p., $11.00
191	Use of Rumble Strips to Enhance Safety (Proj. 20-5, Topic 22-13), 74 p., $19.00
192	Accident Data Quality (Proj. 20-5, Topic 23-01), 75 p., $16.00
195	Use of Warranties in Road Construction (Proj. 20-5, Topic 23-07), 65 p., $15.00

TABLE 6

NCHRP RESEARCH RESULTS DIGESTS [a]

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
3	20-6	Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act 18 p. $1.00
6	20-6	Standing to Sue for Purposes of Securing Judicial Review of Exercise of Administrative Discretion in Route Location of Federal-Aid Highways 9 p. $1.00
11	20-6	Valuation Changes Resulting from Influence of Public Improvements 25 p. $1.00
14	12-3	Waterproof Expansion Joints for Bridges 3 p. $1.00
19	20-6	Advance Acquisition Under the Federal-Aid Highway Act of 1968 21 p. $1.00
20	19-1	Budgeting for State Highway Departments 4 p. $1.00
22	20-6	Valuation in Eminent Domain as Affected by Zoning 19 p. $1.00
25	20-6	Federal Environmental Legislation and Regulations as Affecting Highways 35 p. $1.00
31	20-6	Proposed Legislation to Authorize Joint Development of Highway Rights-of-Way 12 p. $1.00
32	20-6	Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 13 p. $1.00
39	20-6	Legal Effect of Representations as to Subsurface Conditions 17 p. $1.00
40	20-6	Appeal Bodies for Highway Relocation Assistance 16 p. $1.00
41	20-6	Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases 24 p. $1.00
42	20-6	Supplemental Condemnation: A Discussion of the Principles of excess and Substitute Condemnation 20 p. $1.00
45	20-6	Exclusion of Increase or Decrease in Value Caused by Public Improvement for Which Lands Are Condemned 24 p. $1.00
47	20-6	Trial Strategy and Techniques Using the Comparable Sales Approach to Valuation 13 p. $1.00
48	10-9	Surface Condition Rating System for Bituminous Pavements 24 p. $1.50
54	20-6	Trial Strategy and Techniques Using the Income Approach to Valuation 31 p. $1.00
55	20-7	Side-Friction Factors in the Design of Highway Curves (Task 4) 9 p. $1.00
67	15-2	Field Evaluation of Tentative Design Procedure for Riprap-Lined Channels 4 p. $1.00
68	20-6	The Meaning of Highway Purpose 15 p. $1.00
76	22-3, 3A	Field Evaluation of Vehicle Barrier System 3 p. $1.00
77	20-7	Earth-Berm Vehicle Deflector (Task 3) 3 p. $1.00
78	3-20	Traffic Signal Warrants—A Bibliography 42 p. $1.00
79	20-6	Personal Liability of State Highway Department Officers and Employees 22 p. $3.00
80	20-6	Liability of State Highway Departments for Design, Construction, and Maintenance Defects 49 p. $5.00
81	22-1A	Crash Testing and Evaluation of Attenuating Bridge Railing System 10 p. $1.00
82	1-15	Design of Continuously Reinforced Concrete Pavements for Highways 12 p. $1.00
83	20-6	Liability of State and Local Governments for Snow and Ice Control 16 p. $3.00
84	22-2	Breakaway Cable Terminals for Guardrails and Median Barriers 18 p. $1.00
85	12-16	Bridge Deck Repairs 22 p. $1.00
89	1-12(3)	Guidelines for Skid-Resistant Highway Pavement Surfaces 12 p. $1.00
91	3-21	Motorist Response to Guide Signing 9 p. $1.00
95	20-6	Legal Implications of Regulations Aimed at Reducing Wet-Weather Skidding Accidents on Highways 31 p. $3.00
97	3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations 8 p. $1.00
99	20-6	Liability of the State for Highway Traffic Noise 14 p. $3.00
100	20-5	Safe Conduct of Traffic Through Highway Construction and Maintenance Zones 5 p. $1.00
102	22-2	Modified Breakaway Cable Terminals for Guardrails and Median Barriers 13 p. $1.00
103	20-6	Payment of Attorney Fees in Eminent Domain and Environmental Litigation 24 p. $3.00
105	3-26	Selected Acoustical Parameters of Highway Noise Barriers 8 p. $1.00
106	20-5	Use of Waste Materials in Highway Construction and Maintenance 2 p. $1.00
108	20-6	Trial Strategy and Techniques in Highway Contract Litigation 31 p. $3.00
109	20-6	Control of Conflicts of Interest in Highway Construction Contract Administration 56 p. $3.00
110	20-6	Liability of State and Local Governments for Negligence Arising out of the Installation and Maintenance of Warning Signs, Traffic Lights, and Pavement Markings 14 p. $3.00
111	20-6	Trial Aids in Highway Condemnation Cases 11 p. $3.00
112	20-6	Legal Implications of Control of Access to Uncontrolled-Access Highways 22 p. $3.00
113	20-6	Right to Compensation in Eminent Domain for Abrogation of Restrictive Covenants 12 p. $3.00
114	20-11B	Energy Analysis Methodology for Assessing Environmental Impacts 7 p. $1.00
115	Var.	NCHRP Research on the Durability of Reinforced Concrete Bridge Components 6 p. $1.00
116	20-6	Payments to Public Utilities for Relocation of Facilities in Highway Rights-of-Way 35 p. $3.00
119	20-6	Recovery of Condemnation Blight Under Inverse Law 11 p. $3.00
121	21-2(3)	Development and Field Evaluation of Prototype Soil Moisture Sensors. 3 p. $1.00
122	3-26	Noise Barrier Acoustical Parameters—Experimental Results 5 p. $1.00
123	4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems 7 p. $1.00
126	3-18(4)	Performance Evaluation of Signalized Network Control Strategies 4 p. $1.00
127	8-19	The Vehicle-Miles of Travel—Urban Highway Supply Relationship 7 p. $1.00
129	20-6	Legal Implications of Highway Department's Failure to Comply with Design, Safety, or Maintenance Guidelines 17 p. $3.00
133	1-16	Evaluation of Winter-Driving Traction Aids 7 p. $1.00
134	20-6	Procedural Aspects of Inverse Condemnation—Title on Interest Acquired by Transportation and Other Public Agencies 13 p. $3.00

TABLE 6 (*Continued*)

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
135	20-6	Liability of the State for Injury-Producing Defects in Highway Surface 14 p. $3.00
136	20-6	State Highway Programs Versus the Spending Powers of Congress 18 p. $3.00
137	20-6	The Effects of Federal and State Public Information Acts on Highway and Transportation Department Activities 23 p. $3.00
138	20-6	Legal Aspects of Historic Preservation in Highway Programs 27 p. $3.00
141	20-6	Liability of State Highway Departments for Defects in Design, Construction, and Maintenance of Bridges 20 p. $3.00
145	20-6	First Amendment Aspects of Control of Outdoor Advertising 31 p. $5.00
146	20-6	Minority and Disadvantaged Business Enterprise Requirements in Public Contracting 31 p. $5.00
147	20-6	Mineral Rights in Rights-of-Way: Acquisition, Valuations, and Disposition 15 p. $5.00
149	20-6	Exaction of Right-of-Way by Exercise of Police Power 13 p. $5.00
150	20-6	Planning and Precondemnation Activities as Constituting a Taking under Inverse Law 14 p. $5.00
151	20-6	Liability of State for Injury or Damage Occurring in Motor Vehicle Accident Caused by Trees, Shrubbery, or Other Vegetative Obstruction Located in Right-of-Way or Growing on Adjacent Private Property 20 p. $5.00
152	20-6	Enforceability of the Requirement of Notice in Highway Construction Contracts 17 p. $5.00
153	20-6	Liability of the State for Injuries Caused by Obstruction or Defects in Highway Shoulder or Berm 19 p. $5.00
154	20-6	Trial Strategy and Techniques in Enforcing Laws Relating to Truck Weights and Sizes 35 p. $5.00
157	20-6	Supplement to Licensing and Qualification of Bidders in Selected Studies in Highway Law 19 p. $5.00
158	20-6	Legal Procedural Issues Related to Relocation Assistance 25 p. $5.00
160	20-6	Acquisition of Uneconomic Remnants Under 23 U.S.C. 109(f) 13 p. $5.00
161	2-14	Public and Private Partnerships for Financing Highway Improvements 34 p. $5.00
163	20-6	Supplement to Competitive Bidding and Award of Construction Contracts in *Selected Studies in Highway Law* 32 p. $6.00
164	20-6	Rights of Abutting Property Owner Upon Conversion of Uncontrolled-Access Road into Limited-Access Highway 14 p. $6.00
165	20-6	Legal Techniques for Reserving Right-of-Way for Future Projects Including Corridor Protection 44 p. $6.00
167[b]	Var.	NCHRP Research on Bridge Engineering 8 p. $3.00
169	10-24	Rapid Replacement of Portland Cement Concrete Pavement Segments 11 p. $4.00
170	20-24	Research Program Design Administration of Highway and Transportation Agencies 5 p. $3.00
171	10-20	Pot Bearings and PTFE Surfaces 14 p. $4.00
173	20-24(2)	Guidelines for Establishing Executive Management Information Systems for State Departments of Transportation 7 p. $4.00
174	10-25A	Determination of Water-Cement Ratio in Fresh Concrete 4 p. $4.00
175	Var.	NCHRP Research on Construction Engineering 7 p. $4.00
177	Var.	NCHRP Research on Maintenance Engineering 7 p. $4.00
178	4-16	Service Life and Cost of Pavement Marking Materials 16 p. $4.00
179	2-14	Financing Highway Improvements through Public and Private Partnerships 7 p. $4.00
180	2-27	Implementation of Geographic Information Systems (GIS) in State DOTs 31 p. $6.00
181	1-27	Video Image Processing for Evaluating Pavement Surface Distress 4 p. $4.00
182[b]	20-5	Continuing Project to Synthesize Information on Highway Problems 8 p. $4.00
183	20-24	Administration of Highway and Transportation Agencies "Project 20-24 Series" 6 p. $4.00
184	Var.	NCHRP Research on Pavements 8 p. $4.00
185	20-23	NCHRP Supports Advances in Differential GPS Satellite Surveying 4 p. $4.00
186	20-7	Data Interchange Standards for Bridge Management Systems and Integrated Highway Information Systems 20 p. $6.00
187	12-26	Distribution of Wheel Loads on Highway Bridges 32 p. $6.00
188	10-30(3)	Ultrasonic Nondestructive Testing for Deterioration of High-Strength Steel Components Embedded in Concrete 4 p. $4.00
189	21-3	Instrumentation for Measuring Scour at Bridge Piers and Abutments 8 p. $4.00
190[b]	20-5	Continuing Project to Synthesize Information on Highway Problems 8 p. $4.00
191	20-27	Management Guide for Implementation of Geographic Information Systems (GIS) in State DOTs 48 p. $8.00
192	3-41	Procedures for Determining Work Zone Speed Limits 16 p. $6.00

[a] See Table 3 for project titles. All items listed are final publications except where noted. Numbers missing from the series have been superseded by a later publication. See final page of this document for ordering information.

[b] Progress reports are superseded annually.

TABLE 7
NCHRP LEGAL RESEARCH DIGESTS [a]

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
2	20-6	Supplement to Liability of State Highway Departments for Design, Construction, and Maintenance Defects 20 p. $6.00
3	20-6	Supplement to Liability of State and Local Governments for Negligence Arising Out of the Installation and Maintenance of Warning Signs, Traffic Lights, and Pavement Markings 10 p. $3.00
4	20-6	Supplement to Personal Liability of State Highway Department Officers and Employees 9 p. $3.00
5	20-6	Supplement to Labor Standards in Federal-Aid Highway Construction Contracts 20 p. $6.00
6	20-6	Impact of the Discretionary Function Exception on Tort Liability of State Highway Departments 25 p. $6.00
7	20-6	Liability of Public Agencies Arising Out of Rejection of Bids and Misaward of Contracts 17 p. $6.00
8[b]	20-6	Continuing Project on Legal Problems Arising Out of Highway Programs 11 p. $6.00
9	20-6	Supplement to Liability of State and Local Governments for Snow and Ice Control 11 p. $6.00
10	20-6	Supplement to Liability of the State for Injury-Producing Defects in Highway Surface 10 p. $6.00
11	20-6	Impact of 42 U.S.C. § 1983 (Civil Rights Act) on Highway Departments, Personnel, and Officials 21 p. $6.00
12	20-6	Suspension, Debarment, and Disqualification of Highway Construction Contractors 27 p. $6.00
13	20-6	Civil RICO (Racketeer Influenced and Corrupt Organizations Act) Applications in the Highway Construction Industry 28 p. $6.00
14	20-6	Supplement to Liability of State Highway Departments for Defects in Design, Construction, and Maintenance of Bridges 12 p. $6.00
15	20-6	The Application of NEPA (National Environmental Policy Act) to Federal Highway Projects 22 p. $6.00
16	20-6	Supplement to Payment of Attorney Fees in Eminent Domain and Environmental Litigation 17 p. $6.00
17	20-6	Public Duty Defense to Tort Liability 20 p. $6.00
18	20-6	Supplement to Planning and Precondemnation Activities as Constituting a Taking under Inverse Law 10 p., $6.00
19[b]	20-6	Continuing Project on Legal Problems Arising Out of Highway Programs 11 p., $6.00
20	20-6	Supplement to Legal Aspects of Historic Preservation in Highway and Transportation Programs 39 p., $6.00
21	20-6	Supplement to Liability of the State for Highway Traffic Noise 8 p., $6.00
22	20-6	Authority of State Departments of Transportation to Mitigate the Environmental Impact of Transportation Projects 12 p., $6.00
23	20-6	Supplement to Valuation Changes Resulting from Influence of Public Improvements 24 p., $6.00
24[b]	20-6	Continuing Project on Legal Problems Arising Out of Highway Programs 8 p., $6.00
25	20-6	Minority and Disadvantaged Business Enterprise Requirements in Public Contracting 28 p., $6.00
26	20-6	Legal Implications of Highway Department's Failure to Comply with Design, Safety, or Maintenance Guidelines 12 p., $6.00
27	20-6	Liability of the State for Injury or Damage Occurring in Motor Vehicle Accident Caused by Trees, Shrubbery, or Other Vegetative Obstruction Located in Right-of-Way or Growing on Adjacent Private Property 12 p., $6.00
28	20-6	Preventing and Defending Against Highway Construction Claims: The Use of Changed or Differing Site Condition Clauses and New York State's Use of Exculpatory Contract Provisions and No Claims Clauses 80 p., $8.00

[a] Supplements and new papers will be published in an Addendum to the 4-volume *Selected Studies in Highway Law*.
[b] Progress reports are superseded annually.

PROGRESS BY PROJECT

AREA 1: PAVEMENTS

Project 1-25(1) FY '87 and '88

Effects of Heavy Vehicle Characteristics on Pavement Response and Performance—Phase II

Research Agency: University of Michigan
Principal Invest.: Dr. Thomas D. Gillespie
Effective Date: September 1, 1988
Completion Date: December 31, 1991
Funds: $400,000

The lack of detailed or conclusive data on characteristics of heavy vehicles relevant to pavement management was recognized in several workshop sessions at both the North American Pavement Management Conference in 1985 and the Second North American Conference on Managing Pavements in 1987. Increasing diversity in heavy vehicle characteristics requires a reassessment of input parameters to pavement design and analysis. There are several research projects, both completed and underway, that are intended to evaluate the effects on pavement performance of tire types, tire pressures, heavy vehicle suspension kinematics, and axle configurations through the use of pavement response models and vehicle modeling techniques. A need exists for procedures and techniques for optimization of pavement and heavy vehicle design to provide efficient operation of rural and urban roadways.

The objective of this research was to analyze and evaluate the interaction between heavy vehicle characteristics and pavement performance for application in pavement management. Heavy vehicle (truck and bus) characteristics include tire types (bias ply, radial, low profile radial, and "super-single"), tire pressures, tire contact (area and load distribution), tire configuration (single, dual, and other), suspension systems (variable load, load sharing, and dynamic response), axle configuration (spacing, location, and steering axle), axle static loads, and operating conditions (speeds and acceleration/deceleration). Pavement factors include design (flexible and rigid), operating conditions (high speed and low speed), surface conditions (smooth, rough, jointed), traffic mix, and geometrics. Both static and dynamic interactions between various heavy vehicle and pavement factors were analyzed and evaluated to determine their relationships and relative significance. Analytical and experimental procedures were used to investigate the effects of these interactions on pavement performance and to provide guidelines for use in pavement analysis and design applications.

The approach in the research was to integrate existing mechanistic models of trucks and pavement structures into a cohesive vehicle/roadway simulation system which allowed systematic study of the interactions between these two elements. By virtue of the fact that the pavement is much stiffer than a truck, the two simulation models could be decoupled, allowing the truck dynamic loads to be computed from the UMTRI Pitch Plane Truck models excited by road roughness appropriate to each type of pavement—flexible and rigid. The calculated dynamic loads were then used as input to the pavement models for calculation of the road response and evaluation of pavement damage from the truck.

Flexible pavements were represented by means of influence functions derived from the multi-layer elastic model, VESYSDYN. Rigid pavement influence functions were obtained from a finite element model, ILLI-SLAB. The truck wheel dynamic loads were combined with the influence functions to generate stress/strain time histories at key points in the pavement. Damage due to peak responses at each point was then evaluated to develop a statistical summary of damage from the passing truck.

Thirty-six truck configurations were selected to represent the most common truck design variations currently in use, along with potential future variations. These configurations were evaluated to determine the relative level of road damage induced on 18 representative rigid pavement designs and 13 representative flexible pavement designs, as a basis for establishing relationships of truck design and operating parameters to pavement performance.

All work has been completed and the final report has been published as NCHRP Report 353.

Project 1-26 FY '87 and '89

Calibrated Mechanistic Structural Analysis Procedures for Pavements

Research Agency: University of Illinois
Principal Invest.: Dr. Marshall Thompson
Effective Date: February 6, 1987
Completion Date: December 31, 1992
Funds: $499,942

During development of the revised *AASHTO Guide for the Design of Pavement Structures,* the AASHTO Joint Task Force on Pavements decided to use the statistically based algorithms for traffic loading/pavement performance relationships developed from the AASHO Road Test data with modifications and improvements resulting from research and experience subsequent to the Road Test. It was further decided that research should be initiated immediately with the objective of developing mechanistic pavement analysis and design procedures suitable for use in future versions of the *AASHTO Guide.* The mechanistic technology will eventually

be used to (1) increase ability to consider the influence of environmental factors, such as temperature and moisture content; (2) enable better use of existing and new pavement materials; (3) improve reliability of performance predictions; and (4) evaluate the influence of changing traffic loads and vehicle configurations to include axle spacing, number of tires, higher tire pressures, and non-uniform distribution of tire contact pressure.

The overall objective of research in this problem area is the development, calibration, and verification of mechanistic analysis and design procedures that will reliably predict relationships between traffic loading, environmental and material conditions, and pavement distress such as fatigue cracking, thermal cracking, rutting, and joint-faulting, suitable for use in future versions of the *AASHTO Guide for the Design of Pavement Structures.*

The first phase of the project selected from existing mechanistic technology those procedures suitable for accomplishment of the overall objective; further developed and conducted pilot calibration and verification of the selected technology to the stage of a practical procedure for checking specific pavement designs for various forms of distress; prepared a long-term plan for calibration and verification of the analysis procedure; and prepared a research plan for future development of the analysis procedure to an implementable mechanistic pavement design method suitable for use in future versions of the *AASHTO Guide for the Design of Pavement Structures.*

Activities in the second phase of this project, which has been completed, focused on: (1) developing approaches and procedures for selecting realistic design inputs, (2) refining and simplifying structural modeling and analysis procedures, (3) developing improved and more reliable transfer functions, and (4) packaging and presenting mechanistic-emperical procedures for the apriori design of flexible and rigid pavements into "working formats" suitable for use by state highway agencies. A 5-state "AASHTO Working Group" cooperated with the research team in evaluating the effectiveness of the procedures from an ease of use/complexity standpoint, and to ensure the reasonableness of results.

The final report has been reviewed and approved by the project panel. The report was distributed to program sponsors and loan copies are available upon written request.

Project 1-27 FY '89

Video Image Processing for Evaluating Pavement Surface Distress

Research Agency: Triple Vision, Inc.
Principal Invest.: Dr. Richard A. Fundakowski
Effective Date: March 1, 1989
Completion Date: August 31, 1991
Funds: $350,000

Measuring distress of both bituminous and portland cement concrete pavements is a primary means of evaluating pavement performance. Despite the importance of distress measurements, current methods are subjective and time consuming. However, significant progress has been made in electronic instrumentation and in computer technology. An increasing number of transportation agencies have embraced the concept of data- and image-acquisition systems that record, among other things, the condition of the pavement surface in a video format. An automated means of processing video images to quantify surface distress would represent a significant contribution in the field of pavement management at both network and project levels.

The objective of this project was to develop a system for processing video images to identify, quantify, and classify pavement distress in terms of types, severity, and extent. Research has been completed with the development of a system which employs image processing and pattern recognition techniques for interpreting pavement surface distress. It shows potential for discerning isolated and patterned cracking on both asphalt and PCC pavements. It also is capable of assessing joint deterioration and discriminating joints from cracks on PCC pavements.

To test and validate the system, a video disk was compiled of 30 test sections, 300 ft in length, with various distresses. System validation showed good overall correspondence with visual observation of the video images in detecting a variety of types of cracking on both asphalt and PCC pavements.

The final report has been reviewed and approved by the project panel. The report was distributed to program sponsors and other interested persons. While the concept of surveying pavement distress in this matter is of interest to many, the details of system development have a limited audience. Therefore, the report will not be published in the regular NCHRP report series, but its availability was announced via Research Results Digest No. 181. Loan copies are available upon written request to the NCHRP.

Project 1-28 FY '90

Laboratory Determination of Resilient Modulus for Flexible Pavement Design

Research Agency: Georgia Tech Research Corporation
Principal Invest.: Dr. Richard D. Barksdale
Effective Date: April 15, 1990
Completion Date: December 1, 1994
Funds: $443,433

The resilient modulus of pavement materials and subgrades is an increasingly important input item for design of flexible pavement structures. Existing laboratory test procedures for determining resilient modulus vary in approach; they appear complex and ambiguous, and require a major investment in time and equipment, while providing questionable results. Even the term "resilient modulus," as used by highway design practioners, differs from the "modulus of

resilience" used in other engineering disciplines. Laboratory test procedures do not adequately simulate field conditions, and considerable differences exist between field-determined moduli and laboratory test results.

Resilient modulus is an essential input variable for pavement design using mechanistic concepts. In addition, the emperical design procedures presented in the 1986 *AASHTO Guide for Design of Pavement Structures* require the resilient modulus of the subgrade as a design input in place of the "soil support value" used in the previous editions. However, in the *AASHTO Guide,* an undue emphasis may be placed on the use of resilient modulus in determining structural coefficients. This may lead to the misinterpretation that resilient modulus is the only property of importance in this determination.

The primary objective of this study is to develop and recommend laboratory test procedures for determining resilient moduli of component materials in a flexible pavement structure. These procedures are intended for use in design of both new pavements and rehabilitation of existing pavements. The procedures must be able to account for varying field conditions, such as temperature of the asphalt surface layer and moisture content of a subbase or subgrade layer.

Another objective is to assess the applicability and constraints of using the resilient modulus to establish structural coefficients for the flexible pavement design procedure in the 1986 *AASHTO Guide.*

Accomplishment of these objectives will require, as a minimum, the following tasks: (1) Review state-of-the-art procedures and equipment for laboratory resilient modulus testing and their interrelationships with current and emerging practices for design of flexible pavements. (2) From the information obtained in Task 1, identify test procedures and equipment for further development under Task 4. (3) Submit an interim report within 6 months after initiation of the research. The interim report shall summarize the accomplishments of Tasks 1 and 2, and include a detailed plan for the laboratory work to be performed under Task 4. (4) Develop detailed laboratory test procedures for determining resilient modulus values suitable for use in flexible pavement design. This task may include either modifications of existing equipment and methods or development and fabrication of new equipment or both. The procedures should encompass the normal range of load and environmental factors and material characteristics, and should be suitable for testing both laboratory specimens and field samples. The validity and suitability of the test procedures should be confirmed with sufficient testing of materials encompassing the range of characteristics normally encountered in highway design. The goal of this task is to recommend laboratory test methods that are easily performed and yield consistent and realistic material characteristic values. Recommended test procedures should be in a format suitable for adoption by AASHTO or ASTM. At the conclusion of this task, a second interim report shall be submitted containing the recommended test procedures and a detailed plan for the validation and study required in Tasks 5 and 6. (5) Perform a validation analysis of the recommended test procedures through multi-lab testing. The results of the validation analysis shall be used to refine test procedures. (6) Conduct a limited study to compare and analyze field-determined modulus obtained by commonly used nondestructive testing devices and back-calculation procedures with laboratory-determined modulus using validated test procedures. The purpose of this study is to provide an indication of the magnitude of the difference between field and laboratory resilient modulus values. (7) Review the 1986 *AASHTO Guide for the Design of Pavement Structures* with particular emphasis on Chapter II, paragraphs 2.3.3 and 2.3.5. Assess the applicability and constraints of using resilient modulus values to establish structural coefficients for use in the flexible pavement design procedure. Recommend any revisions as appropriate. (8) Prepare a final report documenting the research effort and the research findings.

Research continues both at Georgia Tech and through a major subcontract with North Carolina State University. An early deliverable of suggested rewording for the *AASHTO Guide* was submitted, approved by the project panel, and delivered to AASHTO for consideration. The first 4 tasks have been completed, and Interim Report No. 1 has been submitted and approved. Interim Report No. 2 has been received and is being reviewed by the project panel.

Project 1-29 FY '93

Improved Surface Drainage of Pavements

Research Agency:	Pennsylvania State University
Principal Invest.:	Dr. David Anderson, Dr. Joe Reed
Effective Date:	January 4, 1993
Completion Date:	July 3, 1995
Funds:	$400,000

Water depth is a safety issue on high-speed roadways, and one of the primary concerns is the mechanism known as sheet flow, where a layer of water flows across an expanse of pavement. Rapid removal of water to minimize sheet flow on the surface needs to be addressed both for the design of new pavements and for correcting existing conditions. Many urban freeways are now being widened, which further increases the depth of sheet flow across pavements. In some cases the widened pavement may be 10 or more lanes. Even with a typical crowned section, water accumulation on the outer travel lanes can cause problems. The problem may be exacerbated when the surface water flows only to one side or where the low point of sag vertical curves coincides with a flat area of a superelevation transition. There may be additional problems where widened pavements are present (such as at ramp gore areas) or pavements are rutted.

The most effective means for minimizing sheet flow on pavements need to be studied. Normally, geometric design factors should be considered first; however, in many cases this is not enough. Pervious pavements, surface treatments

such as grooving or texturing, sheet-flow interception techniques, and any other means need to be identified and studied.

Additionally, current methods of calculating the depth of sheet flow across pavements, hydroplaning speed, and parameters that are input to these calculations need evaluation.

The objective of this research is to identify effective methods and develop guidelines for improving the surface drainage of pavements. Factors to be studied should include, but not be limited to, the following: (a) Geometric factors such as cross slope, longitudinal grade, width of the pavement, and superelevation. (b) Pervious pavements and various pavement surface characteristics. (c) Positive interception techniques such as slotted drains.

Accomplishment of the objective will require at least the following tasks: (1) Literature Review—Review the available literature relating to sheet flow on pavements and its rapid removal, and identify the major issues and problems, such as hydroplaning, skid resistance, and splash and spray. The review should not be limited to U.S. sources. (2) State of the Practice—From the information generated in Task 1, identify and assess the state of the practice on pavement surface drainage including the interactions between meteorological conditions, geometrics, pavement properties, and techniques to intercept sheet flow. This effort should focus on situations both where new pavements are being designed and where existing pavements are being considered for rehabilitation. The assessment should include a discussion of the methods used to calculate sheet flow, hydroplaning speed, and other relevant parameters. (3) Analysis—Evaluate the applicability and limitations of the calculation methods identified in Tasks 1 and 2. Perform sensitivity analyses to determine the relative importance of the various factors that influence: (a) surface sheet flow; (b) skid resistance, hydroplaning, vehicle handling, and splash or spray; (c) interception techniques, e.g., pervious pavements, and slotted drains. (4) Interim Report—Within 9 months after initiation of the research, submit an interim report. The interim report shall summarize the findings of Tasks 1, 2, and 3, including the issues and problems, and a detailed plan of the field and laboratory testing and analytical work to be accomplished in Task 5. (5) Evaluation—Conduct field tests on existing pavement sections to evaluate the methods judged as most effective for minimizing the impact of sheet flow. Where appropriate field sections are unavailable, additional tests in the laboratory may be required. Evaluate the results of field and laboratory tests through analytical models such as those used in Task 3. (6) Guidelines—Based on the results of Task 5, develop guidelines for: (a) geometric design to minimize sheet flow and its impacts; (b) identification of sites where there are surface drainage problems on existing pavements; (c) the use of pervious pavements, textured pavements, surface grooving, and other surface characteristic treatments; and (d) the use of interception techniques, such as slotted drains, and trench drains. (7) Final Report—Prepare a final report fully documenting the research effort, including practical guidelines for the most promising techniques to provide improved surface drainage of pavements. The report should also identify follow-on studies justified by the findings of the research.

The project is underway. The literature review and the analysis of the existing models to determine water film thickness on pavements is essentially complete. The review of the state of the practice is ongoing and the interim report is being reviewed by the project committee.

Project 1-30 FY '93

Support Under Portland Cement Concrete Pavements

Research Agency: University of Illinois
Principal Invest.: Dr. Michael I. Darter
Effective Date: January 1, 1993
Completion Date: June 30, 1994
Funds: $150,000

There is no general agreement among pavement engineers on how to select values of the modulus of subgrade reaction, *k*, and values of loss of support for use in design of rigid pavements and rigid pavement overlays.

The basic input value used in the *AASHTO Guide for Design of Pavement Structures* to characterize the degree of support under a portland cement concrete (PCC) pavement is *k*, as determined from plate-bearing tests. Because this test is not commonly conducted, *k* values are estimated from the general soil types in the area, from California Bearing Ratio (CBR) values, or from other tests. The effective value of *k* in a specific location depends on the subgrade condition and properties of all pavement layers below the slab. There is a need for better correlation of *k* values with pavement performance.

Uniformity of support under PCC pavements is important to long-term pavement performance. However, uniform support is difficult, if not impossible, to attain. Variability in construction and materials, temperature and moisture differentials, curling and warping of the slab, joint faulting, and slab pumping are factors contributing to nonuniformity or lack of support under the slab. The 1986 *AASHTO Guide* includes a "loss of support" factor, based on data from the AASHO Road Test, to account for the potential loss of support arising from subbase erosion and/or differential vertical soil movements.

There is a need for further evaluation to incorporate currently available data on loss of support. Research is needed to thoroughly examine the degree of support under concrete pavements and provide improved guidelines for the selection of *k* values and loss of support adjustments, if required, for use in pavement design.

Access to the Rigid Pavement Performance and Rehabilitation (RPPR) database is available to the researcher through

the Federal Highway Administration (FHWA), and additional information that will be accumulating in the Strategic Highway Research Program (SHRP) Long Term Pavement Performance (LTPP) database may be obtained through the Transportation Research Board (TRB). It is believed that this research project can be accomplished using those data and other information that may be gathered during the course of the project.

The objectives of this research are (1) to develop and recommend improved guidelines for the selection of *k* values and (2) to identify and assess loss-of-support values for use in the design of rigid pavements and pavement overlays. The *k* and loss-of-support values shall pertain to all layers below the PCC pavement slab being designed.

Factors to be considered in the research tasks should include but not be limited to: (a) uniformity of support, (b) change of support over time, (c) climatic conditions, (d) combinations of various subbases and subgrade types and thicknesses, (e) level of stresses within the subbase and subgrade material, (f) moisture level of the subbase and subgrade, (g) the method of determination of *k*, i.e., static vs. dynamic, and (h) pavement parameters that affect *k*, such as thickness, joint spacing, load transfer, and shoulders.

Accomplishment of the objectives will require at least the following tasks: (1) Identify test methods, including static and dynamic (NDT) tests, used for estimating *k* and loss-of-support values. Evaluate their applicability based on available data. (2) Identify and correlate, from information in existing databases, parameters for subbase and subgrade support and loss of support that affect pavement performance. (3) Based on the parameters identified in Task 2 and their correlation with pavement performance, develop a procedure for estimating the change of *k* and loss of support over time for various subbase and subgrade types, combinations, and conditions. (4) Based on the results of Tasks 1 through 3, develop and recommend guidelines for selection of *k* and loss-of-support values, where appropriate, for use in rigid pavement design. (5) Submit a final report documenting the entire research effort. A glossary of terms pertaining to the subject shall be included.

Research on Tasks 1 and 2 has been completed, and work on Tasks 3 and 4 is proceeding on schedule.

Project 1-31 FY '94

Smoothness Specifications for Pavements

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (27 months)
Completion Date:
Funds: $400,000

Most state highway agencies employ pavement-smoothness specifications for newly constructed surfaces on rigid, flexible, and composite pavements to provide ride quality for the traveling public and to promote overall construction quality. Many specifications incorporate provisions for incentive/disincentive payments on the basis of initial paving smoothness and these incentives and disincentives can be sizable. Given that pavement-smoothness specifications with incentive/disincentive provisions are being used widely, an evaluation of the effectiveness of the specifications and measurement methods is needed.

Initial smoothness is often determined through the use of profilographs. Recently, several concerns have arisen regarding the use of smoothness specifications, and the use of profilographs and their generated statistics:

- It is commonly claimed that smoothness specifications indirectly improve the overall quality of paving projects, but this claim has not been objectively examined.
- Several states have observed large increases in roughness on rigid pavements within months after paving, bringing into question the long-term benefits of initial smoothness.
- States employing profilographs on flexible paving projects have reported paying maximum incentive payments on a vast majority of projects, and have questioned whether the specifications, measurement methods, and equipment being used are appropriate for flexible pavements.
- Profilograph type, condition, operation, trace interpretation, and time of measurement significantly influence measured values on pavements constructed at typical smoothness-specification levels.
- Significant differences between profile indexes obtained from manual interpretation of profilograph traces and those obtained by profilographs that use on-board computers for interpretation have been observed.

Thus, research is needed to reexamine the usefulness of smoothness specifications, to assess the specifications and measurement methods presently used, and to develop recommendations for guide specifications and measurement methods.

The objectives of this research on flexible, rigid, and composite pavements are to (1) determine the impact of initial smoothness on a) total quality of the pavement as constructed, b) ride quality of the pavement over its life, and c) the pavement service life; (2) determine the effects of existing smoothness specifications on the initial as-constructed smoothness; (3) determine cost-effectiveness of smoothness specifications, including incentives and disincentives; and (4) recommend methods to specify and measure initial smoothness on construction projects.

The research will include as a minimum the following tasks:

Task 1. Conduct a literature review on the subject. Survey current and planned smoothness specifications and measurement methods, and present results in a chart summarized on a state-by-state basis.

Task 2. Design and develop a comprehensive database that includes all elements necessary to meet research project

objectives. Anticipated elements of the database should be identified in the proposal.

Task 3. Within 6 months after initiation of the research, submit a technical memorandum presenting the results of Tasks 1 and 2 and detailing the proposed analysis methodology for accomplishing Tasks 4 and 5. NCHRP approval will be required before proceeding.

Task 4. Analyze data collected in Tasks 1 and 2 to determine the impacts of initial smoothness on pavement quality as constructed, ride quality over the life of the pavement, and pavement service life.

Task 5. Analyze data to determine the effect of smoothness specifications on initial smoothness. Evaluate the cost-effectiveness of incentive/ disincentive payments.

Task 6. Within 13 months after initiation of the research, submit an interim report describing the results of Tasks 1 through 5 and presenting a proposed methodology for accomplishing the remaining tasks. NCHRP approval will be required before proceeding with subsequent tasks.

Task 7. Assess equipment and methods of measurement for determining initial smoothness, considering pavement types, time of measurement after placement, economics, repeatability, ruggedness, simplicity, and relatability to profile measurements.

Task 8. Develop and recommend guide specifications for initial smoothness for rigid, flexible, and composite pavements. The draft guide specification will be submitted by March 1, 1995, to allow time for incorporation into 1995 construction projects.

Task 9. Evaluate the effectiveness of the draft specification under actual field conditions and recommend refinements.

Task 10. Assess the impact of the proposed guide specification on current construction procedures, and include an evaluation of cost-effectiveness.

Task 11. Prepare a final report fully documenting the research effort, including the proposed guide specification for initial smoothness for rigid, flexible, and composite pavements.

Project 1-32 FY '94

Systems for Design of Highway Pavements

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	(33 Months)
Completion Date:	
Funds:	$500,000

A rational pavement design must consider the effects of roadbed soil (e.g., fine, coarse-grained), climate (e.g., dry, wet freeze, no freeze), traffic loading, construction materials (e.g., asphalt concrete, portland cement concrete, untreated aggregate base, stabilized base), and other design details and features (e.g., shoulders, drainage provisions, joints, reinforcement) on pavement performance and life-cycle costs. The objective of the design process is to identify pavement structures that will provide acceptable performance and economy over the intended design life. The 1986 *AASHTO Guide for Design of Pavement Structures* provides methods for pavement design that address these items. However, the AASHTO Guide does not provide specific recommendations for many pavement design features.

In spite of similarities in environment, traffic, and roadbed soil within and among some states, practices for design and construction vary widely. A catalog that identifies recommended design features for flexible and rigid pavements would help guide highway authorities in selecting suitable and reliable designs. Many European highway agencies have developed and adopted such design catalogs. Supplementing such a catalog with a microcomputer-oriented, knowledge-based expert system would further enhance the catalog's use and facilitate its updating.

The objectives of this research are (1) to evaluate the feasibility of developing a comprehensive catalog of recommended design features for both flexible and rigid pavements and a corresponding prototype expert system and, if feasible, (2) to develop such a catalog and expert system.

To accomplish these objectives, the following two research phases will be conducted:

Phase I: (1) Identify the parameters and site conditions necessary to characterize current design features for both flexible and rigid pavements. Examples of site conditions include traffic loading, climate, and roadbed soil type. Design features vary with pavement type. Examples of these features include joint details, materials properties, drainage provisions, and cross-section details. Develop a factorial matrix of these items to provide a basis for catalog development. (2) Survey all state highway agencies and compile a summary of current design features for both flexible and rigid pavements. The summary shall be organized according to the factorial matrix developed in Task 1. The results of this task shall be presented in a *Catalog of Current State Pavement Design Features*, which shall be submitted for review by NCHRP. A revised version that incorporates reviewer's comments shall be submitted for possible publication by NCHRP. (3) Evaluate the feasibility of producing a catalog of recommended design features for both flexible and rigid pavements. This evaluation must consider those factors that influence the usefulness of the catalog, such as the ability to reach a consensus of the different sectors of the highway industry on the recommended design features, the potential efficacy of the catalog, and the ease of adaptability for other conditions. Also, evaluate the feasibility of supplementing such a catalog with an expert system. (4) Prepare an interim report that (a) documents the research effort performed in previous tasks and (b) provides an updated work plan for the Phase II portion of the project, describing rationale, methods, schedule, budget, and other required details. Following a review of the interim report

by the project panel, the research team will be required to make a presentation to the project panel.

Phase II: (5) Establish recommendations for each cell in the factorial matrix. These recommendations may include features other than those identified in the *Catalog of Current State Pavement Design Features*. (6) Based on the results of Task 5, prepare and submit for review by NCHRP a *Catalog of Recommended Pavement Design Features* for both flexible and rigid pavements. A revised version that incorporates reviewer's comments shall be submitted for possible publication. (7) Using the information obtained in Task 5 and the *Catalog of Recommended Pavement Design Features* prepared in Task 6, develop a prototype microcomputer-oriented, knowledge-based expert system for selecting the recommended design features. The system shall consider both flexible and rigid pavements. (8) Recommend a plan for extending the prototype expert system developed in Task 7 into an operational system through implementation, evaluation, and validation. This plan may be considered by NCHRP and other organizations for future funding. (9) Prepare a final report that documents the entire research effort. Following review and comment by the project panel, the research team will be expected to make a presentation on the project findings to the AASHTO Joint Task Force on Pavements.

AREA 2: ECONOMICS

Project 2-14 FY '86

Public/Private Partnerships for Financing Highway Improvements

Research Agency: Kimley-Horn and Associates
Principal Invest.: Laurence J. Meisner
Effective Date: January 1, 1986
Completion Date: January 31, 1990
Funds: $175,000

The objective of this research was to provide guidance to state and local highway officials and private developers on existing and potential public/private partnership mechanisms, including present state and local statutes and ordinances related to private (e.g., developer) participation in financing highway improvements. The project has identified constraints on private participation in financing highway and road improvements, identifies potential opportunities and appropriate processes to implement public/private partnerships, and documents examples of state and local legislation enabling and encouraging such partnerships. Guidelines have been developed for application at the state and local levels to facilitate this form of highway financing.

The guidelines consist of a well-defined, step-by-step process which can be used at the State or local level to implement legislation to facilitate public and private financing partnerships. Specific examples of legislation include recommended language for both statutes and ordinances for three of the most promising mechanisms, namely, special assessment districts, impact fees, and development agreements. A benefit-cost analysis technique was also developed for analyzing benefits to the public and private sectors of a potential funding arrangement.

All research has been completed. NCHRP Research Results Digest 161, "Public and Private Partnerships for Financing Highway Improvements," has been published as a separate report covering only the legal issues.

The final report has been published as NCHRP Report 307, "Public and Private Partnerships for Financing Highway Improvements." Following publication of NCHRP Report 307, the project panel elected to conduct further work to disseminate the research findings through the preparation of a one-day workshop. The workshop, intended for State and local highway officials and developers, is being presented to panel members and invited participants. Following presentation to the project panel, workshop materials have been revised and are available on loan from the NCHRP. The Federal Highway Administration is planning to incorporate a number of the products of this research into their training courses. Research Results Digest 179, summarizing all phases of the research is available. (See final page of this document for ordering information.)

Project 2-15 FY '86

Identifying Measuring, and Evaluating the Benefits of Safety Roadside Rest Areas

Research Agency: KLD Associates, Inc.
Principal Invest.: Gerhart F. King
Effective Date: January 13, 1986
Completion Date: April 30, 1989
Funds: $236,560

There is no known reliable and generally accepted method for measuring and evaluating the benefits of safety roadside rest areas. Most states have not yet completed the originally planned rest area system and now also face the necessity of major reconstruction of many older rest areas.

The objective of this research was to develop a method for measuring and evaluating the benefits of roadside rest areas to result in more cost-effective designs and operations. This research addressed both the benefits and disbenefits associated with rest area facilities.

All research has been completed. The final report has been published as NCHRP Report 324, "Identifying, Measuring, and Evaluating Benefits of Roadside Rest Areas."

The findings of Report 324 will be of interest to state highway officials concerned with the location, planning, design, operation, and maintenance of safety roadside rest areas on the Interstate and rural primary highway systems. The report provides a wealth of up-to-date information on rest area practices, rest area users and use, and benefits and

costs of rest areas. Information in the report can be used in a number of ways, for example, recommended spacing for the location of new rest areas, types of services to be added to reconstructed facilities, hours of operation currently expected by travelers, operational problems as a basis for parking area design, security problems and their impact on enforcement needs, cost information for preparation of construction and maintenance budgets and information on benefits to support budget priorities. In summary, Report 324 constitutes a long-needed state of the art on rest areas and provides a tool for analyzing rest area problems and evaluating alternative solutions.

Project 2-16 FY '87 and FY '89

Relationships Between Vehicle Configurations and Highway Design

Research Agency: Transportation Research Board
Principal Invest.: Robert E. Skinner, Jr., Joseph R. Morris
Effective Date: March 2, 1987
Completion Date: June 30, 1990
Funds: $912,000

Data from the AASHO Road Test and other field experience indicate that most pavement distress and damage are associated with heavy axle loads from highway vehicles. Specifically, the Road Test data show that pavement damage increases exponentially as axle loads get heavier. Analysis of the Road Test Data also indicates that increases in pavement thickness permit exponential increases in equivalent axle loads for comparable pavement performance. Mr. F. C. Turner, retired FHWA Administrator, has suggested that use of longer trucks with more axles and lower axle loads could result in reduced damage to pavements and more efficient use of transportation funds. Considerable interest has developed in investigating Mr. Turner's suggestion.

This is a very complex issue involving technical, economic, social, and other factors. No detailed systematic evaluation has been made of the influence of vehicle configurations (e.g., axle loads, axle spacing, tire pressures, and spring components) and highway design (e.g., pavement thickness, bridges and geometrics) on the efficiency of the highway transportation system.

The overall objective of this project was to develop recommendations for coordination of heavy vehicle configurations and pavement, bridge, and highway geometric design to produce the most practical and efficient transportation of goods and services over the highway system.

Research on all major objectives has been completed.

The final report has been published as *TRB Special Report 227,* New Trucks for Greater Productivity and Less Road Wear—An Evaluation of the Turner Proposal."

Project 2-17(1) FY '90

Methodologies for Evaluating the Effects of Transportation Policies on the Economy

Research Agency: Hickling Corporation
Principal Invest.: Dr. David Lewis
Effective Date: September 1, 1989
Completion Date: January 31, 1991
Funds: $99,145

There is a growing concern that the nation's current transportation policies are not providing the necessary level, type, or quality of services that are required to maintain or improve national productivity and international competitiveness, or to enhance regional and state economic development.

In response to this concern, there is a need for research that will document and critically evaluate the quality and content of the current state of knowledge and research in progress, relating to transportation (all modes) and the local, regional, and national economies.

The objectives of this project are (1) to identify and describe methodologies available to analyze the relationships between transportation and economy, (2) to critically evaluate the methodologies and the state of knowledge resulting from their use, and (3) to develop a primer which documents economic analysis methods found useful in transportation policy decision-making.

To accomplish these objectives the following tasks will be performed:

Task 1. For all modes, conduct a literature survey, review research in progress, and inventory current practice to identify and describe the techniques, practices and research available to analyze the interrelatioinships between transportation and the economy. The types of analyses to be considered include but are not limited to:

- Input-output analysis
- Cost-benefit analysis
- Rate-of-return analysis
- Opportunity cost analysis
- Regional impact analysis models
- Macro-economic analysis
- Industrial locational decision-making models

Prepare a draft report, for review by the project panel, including recommendations for the scope of the Task 2 effort and the technical and practical criteria to be used in the evaluations.

Task 2. Following project panel review and approval of the draft report prepared in Task 1, perform the recommended evaluations in accordance with the approved plan and prepare a draft report of those results.

Task 3. Develop a primer that will document existing knowledge and useful avenues (either in theory, practical application techniques, or repackaging of existing knowledge) in economic analysis, to assist transportation policy

decision-making. The primer shall be written in language suitable for use by state and local transportation decision-makers in explaining the economic effects of transportation infrastructure investment to legislators, interest groups and the public. A summary version of the primer, suitable for release to the media and the public, will also be prepared for project panel review and approval.

Task 4. Prepare a final report including recommendations for additional research needed to improve existing or proposed methodologies. The research needs shall be based on the Task 1 investigations, the Task 2 evaluations and the project panel review of the Task 3 primer.

All work has been completed, and the the final report has been published as NCHRP Report 342, "Primer on Transportation, Productivity and Economic Development."

For additional background on this project and others in the Project 2-17 series, readers are referred to "NCHRP Summary of Progress Through 1988," Transportation Research Board, Washington, DC, 1988, page 72.

Project 2-17(2) FY '90

Workshop on Research Needs in Transportation and Economic Development

Research Agency: Greenhorne & O'Mara, Inc.
Principal Invest.: Lowell B. Jackson, P.E.
Effective Date: September 1, 1989
Completion Date: July 31, 1990
Funds: $52,0000

The objectives of this project are to assist NCHRP Project Panel A2-17 and the NCHRP staff in organizing, conducting, and documenting a workshop on research needs in transportation and economic development. The purpose of the workshop was to critique the current thinking in this area, to identify the most critical gaps in knowledge, and to develop a research agenda to facilitate the bridging of these gaps.

The workshop was held March 25–28, 1990 in New Orleans, LA. Four groups, (1) Freight/Services/Commodities Transport, (2) Metropolitan and Intercity Travel, (3) Travel and Tourism, and (4) Intermodal Transport, met in a series of plenary and breakout sessions. A total of 23 research problem statements were developed and prioritized.

Following the workshop the Project Panel met in Washington, DC, on May 14–15, 1990 to review the workshop results and develop recommendations to AASHTO/ SCOR for funding for FY '92. The panel reviewed a total of 23 problem statements emanating from the workshop. A number of them contained overlap and were combined and refined into 15 statements, titled as follows:

1. State and National Macroeconomic Linkages Between Transportation Investments and Economic Performance
2. Measuring the Impact of Changes in Freight Transportation Services and Infrastructure on Industry Productivity
3. Evaluation of the Impact of Congestion on Economic Activity
4. Evaluation of the Relationship Between Transportation Costs and Land Use Densities in Urban Areas— (Phase I, Taxonomy & Synthesis; Phase II, Case Studies & Decision Rules)
5. The Economic Impact of a Rapidly Changing International Transportation Economy and Geopolitical Marketplace on Travel and Tourism
6. Impacts of New Technologies on Intercity Travel and Tourism
7. Economic Impacts of Size-Weight, Labor, and Environmental Regulations
8. Impact of Transportation on Business Location Decisions
9. Implications of Travel and Tourism Needs For Transportation System Design and Information Requirements
10. Equipment Standardization Issues and Intermodal Productivity
11. Development of Governmental Decision-Making Tools that Consider the Relationship of Industry to Transportation
12. Revising Organization and Institutional Processes to Incorporate Revenue Development and Growth Objectives
13. Travel Behavior, Its Determinants and Impacts on Travel and Tourism
14. Identification of Alternative Policy Concepts and Strategies for Enhancing Economic Development and Productivity and Tourism
15. Analysis Methods for Tourism and Travel Strategies to Enhance Economic Development

A report on the proceedings of the New Orleans workshop, covering agenda, participants, drafts of the 23 research problem statements and copies of the resource papers for each of the four breakout groups, is available from NCHRP.

Project 2-17(3) FY '91

Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance

Research Agency: The Johns Hopkins University
Principal Invest.: Drs. Michael Bell and Therese McGuire
Effective Date: November 1, 1991
Completion Date: December 31, 1993
Funds: $250,000

Analytic work undertaken by Aschauer, Munnell, McGuire, and others has indicated that there are positive relationships between investments in infrastructure and economic productivity at the national and state levels. A better understanding is needed of the linkages between transportation investments and economic activity as measured in terms of

macroeconomic factors such as employment, expenditures, income, production of goods and services, productivity, and competitiveness.

Economists differ in their opinions concerning the factors associated with productivity; they do agree that productivity and national income are influenced by the amount of capital which labor has to work with, and that the amount of capital at any given time is a result of past levels of savings, investment, and depreciation. Therefore, it is important that the size and rate of growth of public and private transportation capital and its influence on productivity growth be determined.

Accurate measures of the capital stock (e.g., the sum of past investments) are important to macroeconomic analysis as well as to the development of public policy relative to transportation. The 1974 USDOT report, *Capital Stock Measures for Transportation,* was the most recent effort to estimate the value of the private and public capital stock in transportation. This study estimated, in 1958 dollars, the value of gross and net equipment and structures as well as the value of land, for the period 1950 to 1970. It also estimated the cost of capital services, the economic rate of depreciation, and capacity in the various transportation modes. Similar estimates covering the period 1950-1990 would allow determination of whether there has been a significant slowdown over time in the rate of net capital formation in different transportation modes, as well as the impact of government actions (federal, state, and local) on net investments to public transportation capital.

The overall objective of this research is to improve the understanding of the linkages between transportation investments and economic performance. The goal of this research is to develop an improved estimate of the value of the public and private capital stock (structures, equipment, and land) in transportation over time. This research will provide an improved and updated database which will provide the basis for anticipated future research to investigate in greater depth the linkages between public and private transportation investments and economic performance. In order to accomplish the objective, the following tasks are envisioned:

Task 1. Critically review recent and on-going macroeconomic studies of the contribution of transportation and infrastructure investment to productivity. Identify from this review the types of data on transportation capital stock needed to conduct further research in this area.

Task 2. Assess the dataset created in the 1974 USDOT study for use in macroeconomic research. Identify the strengths and weaknesses of the dataset relative to research needs determined in Task 1. Determine the modifications and updates necessary to be responsive to the anticipated research needs. Identify feasible sources of information for the revised dataset and describe the mechanisms that would be necessary to routinely update the information and account for depreciation and the discounted value of capital. Describe processes to isolate divergent trends in transportation investment, to recognize investments made without a major transportation purpose, and to assess the influences of marginal investments.

Task 3. Prepare an interim report which describes in detail a plan for modifying, updating, and applying a transportation capital stock database. It should also include estimates of the costs for creating a database to address the range of possible research applications. Present the results at an interim meeting of the project panel and discuss alternatives for developing the enhanced database.

Task 4. Build and document a database of transportation infrastructure investment and capital stock (gross and net) over a long period of time (preferably at least back to 1950), by mode and state in accordance with the plan approved in Task 3.

Task 5. Use the derived measures of transportation public capital stock in the production functions described in recent literature to validate the linkages between transportation investment and economic productivity previously reported.

Task 6. Identify other refinements to macroeconomic models that would be possible with the updated and expanded data, including use of surrogate variables to account for the productivity effects of non-transportation investments. Discuss limitations to further applications of models associated with the data.

Task 7. Prepare a final report documenting the efforts undertaken and the findings of this study.

The panel approved the final report and the editorial and publication process has been initiated.

Project 2-17(4) FY '91

Measuring the Relationship Between Freight Transportation Services and Industry Productivity

Research Agency:	Hickling Corporation
Principal Invest.:	Dr. David Lewis
Effective Date:	October 14, 1991
Completion Date:	March 31, 1994
Funds:	$250,000

The demand for freight transportation services is derived from industry needs, and the quality and scope of these services appear to be significant in influencing industrial productivity. Public agencies play an important role in addressing industry needs for moving goods within the overall transportation environment. They can influence freight transportation services by infrastructure investments in the various modes, the introduction of advanced technology, changing operational controls and/or regulations to permit more effective use of transportation facilities and equipment, and/or promoting the application of new shipping concepts. At present, however, there is only limited understanding of the relationship between freight transportation services and productivity for various industry groups. Research is needed

to develop information that can be used by public agencies to make better decisions relative to transportation, in particular freight services, that will promote industry productivity at the state, regional, and national level.

The objectives of the proposed research are to identify for specific industry groups the relative significance of transportation and other logistics costs, the relationships among transportation services, infrastructure, operational conditions, and industry productivity, and the potential impacts of future changes in transportation systems and business practices on these relationships. This research shall demonstrate how the relationships identified could be applied by state, regional, and local agencies to help make decisions on transportation investments which will result in improved industry productivity.

The tasks envisioned are:

Task 1. Review past studies and current efforts relevant to the topic to identify the critical variables and parameters associated with the relationship between transportation services and industrial productivity. Cross reference the variables and parameters to the various techniques that have been used to enhance industry productivity (e.g., just-in-time deliveries, strategic alliances).

Task 2. Develop a research plan to obtaining the pertinent information related to freight transportation service factors and investigating their relationships to industry productivity. The plan should be sensitive to (a) the various logistic facets of freight flows, (b) use of public and private infrastructure, (c) market size, and (d) geographic coverage and identify the industry groups that would be studied. The sample should represent different regions, facility sizes, expanding and mature industries, manufacturing and service sectors, domestic and international scopes of operation, high and low volume/weight freight characteristics, and other aspects.

Task 3. Conduct a pilot study of the research approach for two industry groups identifying the key components of their present and projected logistics systems (e.g., inventory costs, distribution patterns, modes used, transport costs, transportation reliability, infrastructure needs, and damage costs) and assess their relationship to industry productivity. The two industry groups shall include one traditional heavy manufacturing industry (e.g., paper production) and one high tech, service industry (e.g., computer component manufacturing).

Task 4. Prepare an Interim Report documenting the efforts and findings of Tasks 1 through 3 including recommendations for other industry groups to be analyzed and for modifications to the research approach made apparent during the pilot study. An interim meeting will be convened of the project panel to review the research approach and the interpretation of the preliminary findings.

Task 5. Gather and document the pertinent information on freight logistics and industry productivity for the industry groups selected at the interim meeting.

Task 6. Identify current and prospective changes in transportation services and infrastructure developments by providers that may impact industry productivity. Assess the impacts of these changes on logistics systems and overall productivity.

Task 7. Examine current and future business operations and practices that may affect transportation services and infrastructure requirements.

Task 8. Develop a generalized process for public agencies to apply the relationships derived to improve decision-making on transportation investments and policy. Prepare recommendations, for application of the process by public decision makers.

Task 9. Prepare a Final Report documenting the efforts undertaken and findings of the study.

The contractor has continued investigations of particular industries.

Project 2-17(5) FY '91

Impact of Urban Congestion on Business

Research Agency: Cambridge Systematics, Inc.
Principal Invest.: Lance R. Grenzeback
Effective Date: September 15, 1991
Completion Date: March 15, 1993
Funds: $170,000

Congestion in metropolitan areas affects business transportation costs and productivity and, hence, the "bottomline" cost of doing business. However, the effects of congestion on businesses have not been well described, much less quantified.

The objective of this research is to assess and quantify the impact of congestion on the cost of doing business. The impacts of interest include those generally associated with delivery of goods and services, access to customers, transport costs, business output, access to labor supply, extensions and restructuring of delivery systems, and lost markets. Accomplishment of the objective will require the following tasks: (1) Conduct a literature survey, review research in progress, inventory current practice, and seek out relevant data sources. Document: (a) estimates of national and regional costs of congestion (particularly as they pertain to local business activities); and (b) industry studies of internal and external costs attributable to congestion (particularly studies performed within regions or metropolitan areas). Data sources and studies should be sought from, but not be limited to, private industry, trade associations, and regional and local governmental organizations. (2) Develop a sampling plan of businesses at three levels of congestion. Prepare a list of congestion-sensitive business activities, e.g., regular route delivery operations; on-call delivery to customers; off-site client servicing; and on-site customer servicing. Based on this list, develop a sample of specific congestion-sensitive businesses or industries. Further relate the sample of businesses to three levels of congestion selected to encompass

a range representative of United States urban areas. Submit the sampling plan to NCHRP for panel review. (3) Survey the Task 2 sample to obtain data on, or estimates of, congestion-related costs. Seek implicit as well as explicit congestion costs. For example, this might be accomplished by obtaining the reduction in costs due to a range of reductions in average delivery/access times and their variability; (b) using business records, estimate the magnitude and variability of transportation-related costs. Costs should include but not be limited to such factors as increased employee compensation attributable to congestion, local ordinances requiring employer-sponsored transportation demand management strategies, and local prohibitions on delivery hours due to congestion reduction or air quality attainment strategies; (c) using business records and planning studies, estimate critical parameters such as the average and peak delivery times, and average time for customer access. Prior to conducting the survey, submit the draft survey instrument for NCHRP panel review. (4) Analyze the data obtained in Tasks 1 to 3 and determine the relationship(s) between these business activities and levels of congestion. (5) Where relationships between congestion and business activities can be developed, prepare models that can be used at the national, state, and metropolitan levels to illustrate the impact of congestion on business activities. Where such relationships cannot be developed, provide anecdotal findings. Address the use of these findings by transportation officials to implement strategies which would ameliorate congestion costs uncovered by this research. (6) Prepare a final report which documents the results of Tasks 1 through 5.

Research is complete and the project panel has reviewed the final report. A major finding of the research is that the cost of urban congestion is not directly perceived by business as being significant. Most firms do not internalize the costs of congestion and therefore do not measure and account for these costs in ways that directly influence business decisions and the "bottom line" of the firm. However, the findings do suggest that congestion is causing considerable impacts when considering the hard-to-quantify measures of quality of life, productivity of capital, land use, and environmental quality.

A decision on publication of the final report is pending.

Project 2-17(6) FY '93

Tourism Travel Contributions to Economic Development

Research Agency:	Greenhorne & O'Mara
Principal Invest.:	Lowell B. Jackson
Effective Date:	February 1, 1993
Completion Date:	January 31, 1995
Funds:	$299,448

The relationship between the quality of the surface transportation infrastructure and the future growth of tourism travel must be understood in order to guide statewide planning and transportation investment decisions. States take different approaches to the promotion and facilitation of tourism travel and to the measurement of its impact on economic development. It is critical that an effective approach to the demonstration and measurement of the economic benefits of tourism be developed; and that the states be provided with information and guidelines on how investments in transportation infrastructure and traveler facilities can increase those economic benefits.

The importance of the tourism travel aspect of transportation is underscored by the following statistics: (1) U.S. residents took more than 1.3 billion person-trips to places 100 miles or more away from home in 1989, and spent nearly $350 billion doing so; (2) the travel and tourism industry generates more jobs in the U.S. than any industry except health services; (3) based on business receipts, the travel industry is the third largest retail or service industry; and (4) nationwide, foreign visitors account for only 3 percent of tourism trips in the U.S., but more than 10 percent of the travel expenditures. In 1989, the U.S. registered its first surplus in its international travel and transportation account. The U.S. now garners 10 percent of world international arrivals and 16 percent of global international travel spending.

At the national, state, and local levels, there is increasing recognition of the need for a comprehensive understanding of the interaction between tourism travel and economic benefits. This project is intended to address that need in the context of the recently enacted ISTEA (Intermodal Surface Transportation Efficiency Act) legislation. For example, Section 135c, STATE PLANNING PROCESS, states: "Each State shall undertake a continuous transportation planning process which shall, at a minimum, consider the following: International border crossings and access to ports, . . . national parks, recreation and scenic areas, monuments and historic sites, and recreational travel and tourism. . . ." Section 135d, ADDITIONAL REQUIREMENTS, notes: "Each State in carrying out planning under this section shall, at a minimum, consider investment strategies to improve adjoining State and local roads that support rural economic growth and tourism development."

The objective of this research is to develop guidelines for promoting economic development derivable from tourism travel by improving transportation system services. This objective will include (1) the development of measurement techniques and common standards for evaluating tourism-related highway transportation investment decisions, (2) the synthesis and evaluation of highway transportation strategies for promoting tourism, and (3) the recommendation of improvements to facilitate traveler use of the highway transportation system.

To accomplish the objective, a two-phased effort is envisioned. The first phase will produce: (1) a summary report of current state practices that will be of immediate value to

all states for the provision of tourism travel services, and (2) a brief report on the findings of the first phase together with recommendations for changes to the work plan for the second phase. The second phase will result in guidelines aimed at assisting those involved in transportation and tourism travel services to better integrate their planning and programming efforts so as to realize the economic gain from tourism travel while providing a safe and efficient highway transportation system.

The following tasks will be performed: (1) Collect and review existing literature and databases that address the relationship between tourism travel and highway transportation services. (2) Evaluate current practices of state DOTs and other state agencies responsible for tourism to learn: (a) how economic impacts and benefits of tourism are determined, (b) how decisions about tourism-related transportation capital investments are made, and (c) what data are available regarding traveler needs. (3) Survey and document institutional relationships between state DOTs and other state agencies responsible for tourism. The survey should assess the strengths and weaknesses of the various institutional arrangements currently employed. (4) Survey and document how states consider tourism travel in their statewide transportation planning and programming. The NCHRP panel for this project believes only a small number of states conduct a formal statewide planning process that includes tourism travel. (5) Survey and document the various programs and techniques used by the states to provide traveler information services. (6) Prepare two draft reports on the findings of Tasks 1 through 5 within 9 months after initiation of the research. The first report shall be appropriate for publication as a summary of current state DOT practices. The report should provide sufficient detail to enable state DOTs to decide whether to implement practices described. Where additional detail is necessary, references to state documentation or persons to contact shall be included. The draft report should be revised in accordance with NCHRP project panel comments. The second report shall include a brief summary of the Phase I findings together with recommended revisions of the work plan for the remaining tasks. The principal investigator shall meet with the NCHRP project panel to present and discuss the Phase I results and the Phase II revised plan. NCHRP approval of the revised Phase II plan will be required before proceeding with research on the remaining tasks. (7) Using case studies, existing economic analysis models, and other statistical analysis techniques, provide information on measures of tourism travel output and the linkages between these measures and economic development. From this analysis, a recommended measure for tourism travel output should be derived. If a single measure is not feasible, then several measures of output that can be applied at national, regional, or travel industry levels shall be identified. (8) Using the findings of Tasks 1 and 2 and other available information, develop and refine strategies and guidelines for state DOT policies and practices for integrating transportation and tourism objectives. (9) Using the output of Tasks 1 and 3 and other available information, analyze, compare, describe, and present the advantages and disadvantages of alternative institutional arrangements for accommodating tourism travel issues within and among state agencies. (10) Using the output of Tasks 1 and 4, develop guidelines for incorporating tourism needs in Statewide Transportation Planning as identified in ISTEA. (11) Using the output of Tasks 1 and 5, develop recommendations for improving traveler information services. Recommendations should consider traveler needs and expectations responsive to all sectors of the driving population including the older driver, the foreign visitor, and the disabled. (12) Prepare and submit a final report that fully documents the research effort and presents all findings, conclusions, and recommendations.

Research on Tasks 1 and 2 has been completed and work is proceeding on Tasks 3, 4, and 5.

Project 2-18 FY '91

Research Strategies for Improving Highway User Cost-Estimating Methodologies

Research Agency: Hickling Corporation
Principal Invest.: David Lewis
Effective Date: January 2, 1991
Completion Date: December 31, 1993
Funds: $200,000

Planning, evaluating, selecting, and financing highway investments require an understanding of fundamental empirical relationships between the physical and service characteristics of roadways and the associated user costs. Integral to estimating highway needs are accurate measures of the economic costs associated with vehicle maintenance, tires, depreciation, oil, fuel consumption, accidents, emissions, and travel time, each expressed as a function of highway conditions.

Vehicle operating cost estimates provided and used by the Federal Highway Administration and others are based on research conducted in the 1970s and 1980s. However, changes have occurred in vehicle technology, vehicle use, fuel prices, government regulation, and the value users may place on time in a congested environment. Although many consider previous research to be fundamentally sound, there remains a need to reassess the validity of established empirical relationships.

Specifically in view of these facts and the work being undertaken in NCHRP Project 7-12 to develop software to computerize the 1977 AASHTO *Manual on User Benefit Analysis of Highway and Bus Transit Improvements,* there is a need to assess the fundamental empirical relationships between highway characteristics (e.g., roughness, alignment, service level) and user costs (e.g., vehicle operation and maintenance, travel time, safety, emissions). New measures are needed for the value of time and operating and safety

costs as they relate to congestion and productivity. Further, there is a need to determine the sensitivity of user costs to changes in these fundamental empirical relationships.

The objectives of this research are (1) to examine the validity of the data, concepts, assumptions, components, and methods currently used to determine highway user costs; (2) to identify methodological improvements that are possible through theoretical or empirical research; and (3) to propose action plans to undertake the identified research opportunities. The research will include at least the following tasks:

Task 1. Expand upon the literature review conducted as part of NCHRP Project 7-12 to examine the validity and accuracy of current methods used to estimate highway user costs. The literature review shall include both domestic and foreign research related to innovative methodologies, concepts, assumptions, data, and updated procedures.

Task 2. Review and critique current cost-estimating methods considering the critical elements of each component, the realism of assumptions, the rigor of the concepts, the accuracy of the data for the current and future vehicle fleet, and the relative contribution of each component to overall highway user costs.

Task 3. Evaluate the sensitivity of individual cost component estimates to stated and implied assumptions, input data, and specification of the empirical relationships.

Task 4. Identify opportunities for improvements in the highway user cost-estimating procedures possible through theoretical and empirical research. These opportunities may include the use of additional components, establishing more accurate and rigorous fundamental relationships, defining more realistic assumptions, and identifying better data sources.

Task 5. Develop a strategic plan that prioritizes the candidate research opportunities in terms of the general magnitude of cost, length and difficulty of the research effort, and the likelihood that the methodological improvement can have significant decision-making impact. Prepare action plans for those elements of work outlined in the strategic plan defining the research background, scope, approach, duration, and budget for each.

Task 6. Prepare and submit a preliminary draft Final Report detailing the literature review, critique of methods, and the range of opportunities identified in Tasks 1 through 5. The report shall also document the strategic plan for future research and include the candidate research plans. A meeting with the NCHRP project panel will be scheduled after submittal of written comments on the report. The purpose of the meeting will be to discuss the research needs and the strategic plan for addressing these needs. During this meeting the panel and the contractor will discuss the feasibility of the individual research plans and develop recommendations for future research priorities.

Task 7. Prepare a revised Final Report detailing the findings, conclusions, and recommendations resulting from the efforts undertaken in Tasks 1 through 6 and the discussions with the panel on the strategic plan and individual research plans.

Research has been completed and the report is in the editorial and publication process.

AREA 3: OPERATIONS AND CONTROL

Project 3-28C FY '84

Effects of Quality of Traffic Signal Progression on Delay

Research Agency:	Texas A&M Research Foundation
Principal Invest.:	Dr. Edmond C. Chang Dr. Daniel B. Fambro
Effective Date:	August 1, 1986
Completion Date:	July 31, 1988
Funds:	$164,546

Levels of service for signalized intersection approaches in Chapter 9 of the 1985 Highway Capacity Manual (HCM), published as *TRB Special Report 209,* are based on stopped delay as computed from the cycle length, G/C ratio, v/c ratio, saturation flow, and quality of progression. Quality of signal progression has a major influence on stopped delay, as evidenced by the progression adjustment factors (PF) in Table 9-13 of Chapter 9 varying from 0.40 to 1.85. However, the adjustment factors are based on limited data. Field data, supplemented by simulation, are needed to verify the variations in delay resulting from changes in the quality of progression for a variety of conditions. These data should include the effects on stopped delay of individual factors potentially influencing quality of progression (e.g., cycle length).

The objective of this research was to evaluate the effects on stopped delay of changes in the quality of traffic signal progression. Variables to be investigated for both pretimed and semiactuated control include, but were not limited to: (1) signal offset, (2) signal spacing, (3) cycle length, (4) cycle splits, (5) bandwidth, (6) side-street entries at an upstream point, (7) v/c ratios, (8) arterial speed, and (9) platoon decay. Primary emphasis was given to through movements at pretimed signals on multilane arterials in urban and suburban areas.

The product of this research was a calibrated set of progression adjustment factors in the form of a revised version of Table 9-13 (TRB Special Report 209) and a *replacement* delay adjustment technique. This product is suitable for application to the general stopped delay model of Chapter 9 and to the urban arterials procedure in Chapter 11 of the HCM.

All research has been completed. The results have been incorporated into a revision of Chapter 9 of the Highway Capacity Manual which is being reviewed by the Highway Capacity Committee. The final report has been published

as NCHRP Report 339, "Effects of the Quality of Traffic Signal Progression on Delay."

Project 3-32 FY '85

Temporary Pavement Markings for Work Zones

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. Conrad L. Dudek
Effective Date: May 1, 1985
Completion Date: February 28, 1987
Funds: $164,990

Temporary traffic control has become a larger percentage of the costs on many construction, maintenance, or utility projects. With the prospects of continued inflation, limited resources, and high interest rates, it is imperative that all aspects of temporary traffic control be evaluated for economy in application and benefits to the public.

FHWA has issued guidelines and proposed changes in the *Manual on Uniform Traffic Control Devices* (MUTCD) regarding Temporary Markings for Construction and Maintenance Areas. The proposed changes would require as a minimum 4-ft broken lines as temporary markings on most projects, which is more than double what many states now specify. If adopted as the national standard, 4-ft markings would increase project costs.

Research was needed to determine if the proposed 4-ft markings would actually result in significant safety and operational improvements in comparison to current practice.

The specific objective of this research was to compare the safety and operational effectiveness of 1-ft, 2-ft, and 4-ft temporary broken line pavement markings in work zones. The scope and test conditions studied were: (1) surfacing operation on a two-lane, two-way facility; (2) data collection during hours of darkness; (3) dry roadway conditions; (4) tangent and curve sections; (5) use of the test state(s) typical pavement marking cycle (40 to 50 ft); and (6) field tests in real or staged work zones that are open to traffic.

All research has been completed, and the final report has been provided to the National Committee on Uniform Traffic Control Devices and to FHWA. On the basis of the limited conditions studied and the project findings, further research is deemed necessary before any further changes in the MUTCD are contemplated.

The findings of this research project were presented by the principal investigator at the TRB Annual Meeting in January, 1988. A paper, "Field Studies of Temporary Pavement Markings at Overlay Project Work Zones on Two-Lane, Two-Way Rural Highways," by Conrad L. Dudek, R. Dale Huchingson, F. Thomas Creasey, and Olga Pendleton, has been published in Transportation Research Record 1160, **Traffic Control Devices 1988.** The Record also includes a discussion by Anita W. Ward and an author's closure. The final report will not be published in the regular NCHRP report series. Loan copies are available from NCHRP.

Project 3-33 FY '85

Capacity and Level-of-Service Procedures for Multilane Rural and Suburban Highways

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: June 1, 1985
Completion Date: September 30, 1990
Funds: $475,132

Chapter 7, "Multilane Highways," of the new *Highway Capacity Manual* (HCM) published in 1985, is predicated largely on the limited research used for the 1965 edition and on extrapolation from recent studies of other highway types, especially freeways. In the absence of an adequate data base concerning the operating and capacity characteristics of the multilane highway, research is needed to develop this information and to prepare an improved chapter on multilane highways.

The objective of this research was to confirm and/or develop operational, design, and planning procedures for determining the capacity and levels of service of multilane highways, both rural and suburban. This research will: (1) review the current state of the art, (2) develop an adequate data base and, (3) validate, revise, or develop new analytic procedures. Items to be considered include separation of traffic directions, access characteristics, roadside development, presence of signalized and unsignalized intersections, lane widths, lateral obstructions, geometrics, and other variables that may impede smooth traffic flow. The proposed procedures will replace Chapter 7 of the 1985 HCM.

The major thrust of this effort was focused on multilane highway facilities having four or more lanes. The research, however, also considered special multilane configurations such as three-lane, two-way operation (2-1 split) and the provision of a continuous left-turn lane. New material developed for these special configurations will be incorporated into the appropriate HCM chapter.

All research has been completed. The final report and a revised Chapter 7 have been provided to the Highway Capacity Committee for review and a decision on inclusion in the Highway Capacity Manual. Loan copies of the final report are available from NCHRP.

Project 3-35 FY '86

Speed-Change Lanes

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: June 1, 1986
Completion Date: May 31, 1989
Funds: $250,000

Changing vehicle and driver population characteristics makes it necessary to periodically reexamine highway design criteria. The speed-change lane is one of the most common highway features because it can be either a permanent feature (terminals, lane drops, etc.) or a temporary feature (construction and maintenance zones).

The more diverse vehicle population on the highways today, ranging from light low-powered automobiles to heavy trucks, makes a reexamination of speed-change lane criteria necessary to keep design parameters current.

The objective of this research was to examine the current design parameters which establish speed-change lane length. Based on a review of current practice, updated vehicle performance characteristics, and new driver-behavioral data, recommended design procedures were developed for specific applications taking into account the type of facility, geometrics, and other relevant considerations. This research addresses existing and new acceleration and deceleration lanes on freeways. The scope of this research did not include (a) the design of weaving sections, (b) work zone applications, (c) ramp metering, and (d) new accident studies.

All research has been completed and the project panel has reviewed the final report and user design guidelines. The research agency has completed revising documentation which was provided to the AASHTO Geometric Design Task Force for consideration in revisions to the AASHTO "Green Book." The final report will not be published in the regular NCHRP series. Loan copies of the final report and the user design guidelines are available from NCHRP.

Project 3-36 FY '87

Development of a Low-Cost Bridge Weigh-In-Motion System

Research Agency: Bridge Weighing Systems, Inc.
Principal Invest.: Richard E. Snyder
Effective Date: February 16, 1987
Completion Date: October 31, 1991
Funds: $400,000

Truck weight, dimension, and speed data are required for a wide variety of purposes, including maintenance management programs, pavement and bridge management systems, pavement and bridge design, cost allocation studies, and for compliance with FHWA-mandated vehicle weight and speed monitoring programs. Current methods for collecting these data are very costly to both the states and the trucking industry and are often ineffective. A technique is needed to economically acquire information on the characteristics of heavy vehicles and to provide a data base that can be used for improved planning, design, and maintenance of highways and bridges.

At present, most truck weight data are obtained from conventional off-road weigh stations at fixed locations on major highways. There are well known disadvantages associated with the operation of these facilities: they occupy valuable real estate, require expensive equipment, and need costly operating personnel. The stations often become overused, increasing delays to trucking firms. Further, these stations are often easily evaded by overloaded vehicles or by those who wish to avoid delays. A number of states have been investigating bridge weigh-in-motion (WIM) systems, but the cost of equipment and manpower has prevented widespread implementation.

The objective of this research is to develop a low-cost bridge weigh-in-motion (WIM) system capable of providing the traffic data used in the design and maintenance of highways and bridges. The system shall use state-of-the-art technology, have a target purchase price of $5,000 to $10,000 per unit, have a low life-cycle cost, be capable of interfacing with automatic vehicle identification (AVI) equipment, and be deployable on both bridges and large culverts. This research includes the development, testing, and demonstration of a "turnkey" prototype system.

The research included the following tasks: (1) Review existing bridge WIM/AVC systems. (2) Develop a conceptual system design defining the data requirements, equipment performance criteria, hardware and software requirements, and estimated purchase price. At a minimum, the system shall be capable to collect data for the gross vehicle weight for vehicles over 12,000 pounds, the number of axles and spacing, traffic counts of all vehicles, speed, and vehicle classification. In addition, individual axle weights are also desired if the system can obtain this information with reasonable accuracy. (3) Develop an operational model for laboratory testing. This model shall include the necessary software for data recording and transmission, the signal processing algorithms, the interface between the WIM and AVC hardware, and, to the extent possible, the provision for interfacing with AVI hardware. (4) Conduct laboratory tests to evaluate the system performance and capabilities. Modify the system design and model, as necessary. Prepare an interim report documenting the laboratory test results and presenting a field test plan. (5) Build improved prototype(s) of the WIM/AVC system for field testing under general applications for different types of bridges and culverts considering environmental factors, installation and maintenance requirements, and vandal resistance. (6) Field test the prototype(s) according to the approved plan. (7) Evaluate the field test results and modify the system design and prototype(s) as necessary. (8) Build and document a prototype of the final system design for NCHRP. (9) Prepare a final report.

The final report has been received, but a decision was made not to publish it. An evaluation of the system has been conducted by the FHWA and the results are documented in an FHWA report.

Project 3-37 FY '90

Capacity and Level of Service at Ramp-Freeway Junctions

Research Agency: Polytechnic University
Principal Invest.: Dr. Roger P. Roess

Effective Date: July 1, 1990
Completion Date: December 31, 1993
Funds: $400,000

A more definitive understanding of capacity and level of service (LOS) at ramp-freeway junctions is needed to properly design new freeway interchanges and improve existing freeway interchanges.

Chapter 5 of the 1985 *Highway Capacity Manual* (HCM) is based primarily on a Bureau of Public Roads study of lane distribution in the vicinity of merge and diverge areas conducted in the early 1960's. The procedure represents operating characteristics, such as vehicle fleet mix and driver and vehicle performance, that may no longer be valid and does not include a number of geometric and traffic factors that influence capacity and level of service (LOS).

The objective of this research is to develop and validate an appropriate methodology for determining capacity and LOS at freeway-ramp junctions. This could take the form of modifications to the 1985 HCM methodology or an entirely new methodology. In either case, the product of this research shall be a consistent and comprehensive approach treating a wide range of ramp-freeway configurations and traffic conditions.

This research has (1) evaluated the state of the art in operational analysis of ramp-freeway junctions, (2) developed and tested a new methodology for analyzing capacity and LOS at these junctions, and (3) verified the proposed method with an extensive field data-collection effort.

The deliverable items of the project are (1) interim and final technical reports, (2) a new Chapter 5 of the HCM, and (3) a new Highway Capacity Software (HCS) module for Ramps and Ramp Junctions.

All research has been completed and the final products are being reviewed by the NCHRP panel and appropriate members of the Highway Capacity and Quality of Service Committee. Because of extremely wet weather during the data-collection phases, the researchers were not able to meet the original completion date. Consequently, the research contract has been amended to extend the completion date to December 31, 1993.

Project 3-38(1) FY '87

Assessment of Advanced Technologies for Relieving Urban Traffic Congestion

Research Agency: Castle Rock Consultants, Inc.
Principal Invest.: Peter Davies
Effective Date: July 1, 1987
Completion Date: June 30, 1991
Funds: $201,752

Traffic congestion is rapidly becoming one of the most serious problems affecting urban areas. Traffic operations techniques and systems are needed that can substantially increase capacity and improve traffic flow efficiency. While it is essential that "best practices," new construction, and traditional traffic engineering approaches in dealing with traffic demand be vigorously used, innovative and advanced technology needs to be incorporated into the highway system if significant relief for urban traffic congestion is to be realized at economic and social costs below the cost of constructing extensive new conventional facilities.

Application of advanced technologies in areas such as motorist communication, information and navigation systems, vehicle guidance, control systems, and others has the potential for relieving traffic congestion. Issues related to applying such systems to help alleviate traffic and transportation problems have yet to be fully explored.

The objectives of this research are to: (1) identify and assess the most promising advanced technologies and systems that can improve urban highway traffic operations by achieving significant increases in capacity and traffic flow; and (2) for the most promising of these technologies and systems, formulate a plan for research, development, testing, and demonstration.

The following two research phases have been accomplished:

Phase 1—Preliminary Assessment of Advanced Technologies

Task 1—Identify advanced and innovative technologies and systems that offer significant promise of improving urban highway traffic operations. These improvements may include increased capacity, enhanced traffic flow, or improved system operational efficiency.

Task 2—Conduct a preliminary quantitative assessment of each technology with respect to costs and benefits. This assessment will relate each technology to the type of urban congestion problems that can be alleviated (e.g., freeway incidents, recurring congestion on freeways and arterials).

Task 3—Conduct a preliminary assessment of the institutional and organizational issues, public/private sector roles, funding mechanisms, and potential economic benefits of widescale use related to the implementation aspects of these technologies.

Task 4—Prepare an interim report including a list of the most promising technologies in order of their potential for reducing congestion and in terms of the chance of successful implementation.

Phase 2—Detailed Assessment and Program Development

Task 5—Perform a detailed assessment of each of the technologies selected in Task 4. This assessment will include a more detailed analysis of the factors covered in Phase 1. In addition, it will examine such issues as environmental considerations, social impacts, developmental risks, and implementation risks.

Task 6—On the completion of Task 5, prepare and present an executive level briefing to a limited number of top highway officials on the results and recommendations to date. The purpose will be to exchange information and to obtain

input to assist the contractor in formulating research, development, and demonstration (RD&D) program plans.

Task 7—Develop a detailed RD&D program plan for each technology assessed in Task 5, describing the next stage of research, planning, and program development. The research and development element of the plan will define the specific new research requirements to advance these technologies to a demonstration stage by the mid-1990's. The demonstration element of the plan will describe the scale and application of the demonstrations to be developed. It will also address commercialization considerations, institutional and organizational issues, public/private sector roles, educational needs, and demonstration risks. RD&D program costs will be estimated for each plan formulated.

Task 8—Prepare and present an executive level briefing to the same participants who were involved in Task 6. This briefing should cover the recommended RD&D program with emphasis on implementation considerations.

Task 9—Prepare a final report.

All work has been completed, and the final report has been published as NCHRP Report 340, "Assessment of Advanced Technologies for Relieving Urban Traffic Congestion."

Project 3-38(1)A FY '90

A Study to Assess Advanced Vehicle and Highway Technologies

Research Agency: Transportation Research Board
Principal Invest.: Robert E. Skinner, Jr.
Effective Date: July 1, 1989
Completion Date: March 31, 1991
Funds: $345,000

Traffic congestion is rapidly becoming one of the most serious problems affecting urban areas. Urban travel in general is increasing at a rate of 4 percent per year, but construction of new facilities is expected to accommodate less than one-fourth of this additional demand. Therefore, a continued loss in mobility is expected. Against this backdrop of serious existing and growing congestion, traffic operations' techniques and systems are needed that can substantially increase capacity and improve traffic-flow efficiency. Innovative and advanced technology needs to be incorporated into the highway system if significant relief for urban traffic congestion is to be realized at economic and social costs below the cost of constructing extensive new conventional facilities. Application of advanced technologies in areas such as motorist communication, information and navigation systems, vehicle guidance, control systems, and others has the potential for relieving traffic congestion. To date Project 3-38(1) has identified and assessed the most promising advanced technologies and systems that can improve urban highway traffic operations, and a comprehensive report on the state-of-the art in these technologies has been prepared.

As a continuation of Project 3-38(1), NCHRP funding of $42,500 has been provided toward this broad TRB/NRC policy study. Building on the state-of-the-art as defined under Project 3-38(1), the policy study has convened a committee including experts in automotive engineering, highway and traffic engineering, highway administration, electronics and communications, human factors, safety, transportation planning, finance, and public policy. The committee is assessing the role that emerging navigation, communication, vehicle identification and control, and other advanced technologies could play in addressing highway congestion, highway safety, and other highway transportation problems. In conducting its assessment, the committee has considered questions such as:

- What are specific transportation problems that could be effectively addressed by advanced technologies?
- Which technologies appear the most promising and over what time frame?
- What research and deployment strategies for advanced technologies are appropriate for the U.S. and what types of public-private coalitions are needed?
- What legal, institutional, or other non-technical barriers exist to the introduction of advanced technologies?

After meeting to discuss such questions, the committee reviewed background information on Intelligent Vehicle/Highway Systems (IVHS) activities in the U.S. and other countries and refined the scope of its investigation. The committee decided to focus on organizational and institutional aspects of IVHS, and in particular to consider the appropriate division of responsibilities between the public and private sectors in the development and operation of IVHS and international competitive aspects of IVHS.

Committee's work has been completed and its final report has been published as TRB Special Report 232, "Advanced Vehicle and Highway Technologies."

Project 3-38(2) FY '87

Travel Characteristics of Large-Scale Suburban Activity Centers

Research Agency: JHK and Associates, Inc.
Principal Invest.: Kevin G. Hooper
Effective Date: June 1, 1987
Completion Date: March 31, 1989
Funds: $300,000

There is a lack of up-to-date information on travel characteristics of activity centers, particularly the large-scale, multi-use suburban centers that have been developed recently. These data include trip generation rates, travel modes, trip purpose, trip length, parking characteristics, pedestrian activity, capture rate (i.e., proportion of trips attracted to the development from traffic normally passing by the site), intrasite vehicle movements, hourly variations, and vehicle occupancy.

The objective of this project is to develop a comprehensive data base on travel characteristics for various types of large-scale, multi-use suburban activity centers. Representative trip generation rates and other travel characteristics will be determined for use by others in analyzing the traffic impacts of such activity centers on the transportation system. This research will be limited to activity centers with over 5 million square feet of existing floor space and that lie outside of the CBD.

All research has been completed, and the final report has been published as NCHRP Report 323, "Travel Characteristics of Large-Scale Suburban Activity Centers."

Project 3-38(3) FY '87

Traffic Adaptive Control (Phase 1)—Critical Intersection Control Strategies; (Phase 2)—OPAC Control Strategies

Research Agency:	Farradyne Systems, Inc.	
Principal Invest.:	R. David Henry and Christine M. Andrews	
Effective Date:	Sept. 1, 1988	Dec. 15, 1990
Completion Date:	Mar. 15, 1990	March 31, 1993
Funds:	$149,951	$224,878

The inability of traditional fixed-time traffic signal control systems to automatically modify their timing plans, in response to both long-term and short-term changes in traffic demand, results in excessive delay and congestion. Of particular concern is the fact that correctable delay at poorly timed signals increases dramatically as demand approaches capacity.

At present, there is no consensus as to the best approach to providing traffic adaptive control in signalized networks. Although considerable research has been done on strategies that periodically recompute and change systemwide timing plans, very little research has been done with regard to the critical intersection control (CIC) strategy included in FHWA's Urban Traffic Control System (UTCS) software and other packages. Preliminary results from implementation of CIC, such as in the UTCS-enhanced-type system in Los Angeles, have suggested its potential as an effective adaptive control measure. However, further validation is needed. Recommendations and guidelines are needed regarding the proper application of CIC in different types of signalized network configurations and operating conditions.

The objectives of Phase 1 of this research were to (1) determine the effectiveness of a selected CIC strategy currently used in a first-generation computer-controlled signal system; (2) if the CIC strategy is shown to be effective, develop comprehensive guidelines and a user manual for its application; and (3) develop detailed recommendations for improvements to the CIC strategy for future implementation and evaluation.

All research has been completed, and the final report has been reviewed by the NCHRP panel. The CIC algorithm, in general, was found to perform no better than the fixed-time signal timing plan alternative. The researchers concluded that the CIC algorithm was not sufficiently responsive to react to the cycle-by-cycle variation in traffic demand, and hence, tended to make split changes in response to traffic demand that had long since passed through the intersection. The final report was not published in the regular NCHRP report series but is available on loan.

At a meeting in May 1990, the project panel reviewed the results of the research on the CIC strategies and planned a second phase of the research. Beginning early in 1991, the researchers initiated a study of a new traffic signal control approach known as Optimized Policies for Adaptive Control Strategy (OPAC).

The objectives of Phase 2 were to (1) enhance the isolated intersection control version of OPAC which, if tested successfully, was to be developed as an implementable product; (2) adapt and evaluate OPAC as a responsive traffic control strategy at selected intersections within a computer-controlled system, and (3) prepare documentation suitable for the field implementation of OPAC including software documentation, instructions for its calibration to field conditions, and operational procedures.

Extensive testing, using the TRAF-NETSIM model provided by FHWA, was aimed at adapting the OPAC algorithm for use within conventional traffic signal controllers. This did not prove feasible because conventional controllers did not have sufficient processing power. As a consequence, OPAC could not be evaluated at actual intersections within a computer-controlled system as originally intended.

Further research involved the development of a prototype "OPAC Coordinator" consisting of two processors: one for the execution of the optimization algorithm and the other for administrative duties including controller, detector, and operator I/O. The new coordinator employs the OS9 operating system, two processors (68040 and 68HC000), a VME BUS, and a standard NEMA interface to receive status information from and issue commands to conventional traffic signal controllers. The prototype is intended to be compatible with related efforts by California, Texas, and Carnegie Mellon University to develop general purpose Advanced Transportation Controllers and Controller Software.

The final report from the Phase 2 effort, which will not be published in the regular NCHRP report series, is in four parts: (1) *Revised Interim Report*, incorporating panel comments on an earlier draft version; (2) *OPAC-RT Version 3.0 Software Documentation*; (3) *Using TRAFNETSIM to Simulate OPAC Control*; and (4) *Final Report*.

Final reports from Phases 1 and 2 are available for loan or purchase at the cost of reproduction. See the final page of this document for ordering information.

Project 3-38(4) FY '87 and FY '88

Traffic Signal Control for Saturated Conditions

Research Agency:	KLD Associates, Inc.
Principal Invest.:	Edward B. Lieberman

Effective Date: October 1, 1987
Completion Date: June 4, 1992
Funds: $270,000

Medium- and large-sized urban areas throughout the United States experience saturated traffic flow conditions on almost a daily basis. Saturated operating conditions are characterized by the existence of queues that are not able to discharge within a reasonable period of time at a given signalized intersection. These queues may grow to sufficient length to adversely affect upstream intersection operations.

The objectives of this research were to (1) develop procedures and guidelines for applying appropriate signal-timing strategies to minimize the impact of recurring saturated traffic conditions under a wide range of network geometry, traffic flow patterns, and operating conditions; and (2) develop procedures that can be used in computerized signal systems for real-time response to both recurring and nonrecurring saturated conditions.

In response to these objectives, the research has produced a comprehensive two-volume final report. The first volume summarizes the state of the art and current perceptions of the oversaturated traffic environment. It was found that "no coherent approach to the problem of controlling an oversaturated traffic environment exists. . . ."

As a result of the effort to develop a comprehensive understanding and description of the problem, and the finding that no coherent approach exists, the researchers and the project panel decided to develop a new optimal control policy designed expressly for the control of oversaturated signalized networks. Thus the second volume of the final report presents a new approach, designated as the *Internal Metering Policy* (IMP).

The goal of IMP is to manage the growth of queues to *maximize the productivity of the roadway system.* That is, the policy is designed to service as many vehicles through the specified roadway system as possible, in a given period of time. This goal is met if the policy influences traffic operations to satisfy the following objectives: (1) control queue formation to prevent spillback into intersections, (2) fully utilize all available service (green indication) time at the highest service rate, (3) effectively use all existing roadway storage capacity, (4) provide equitable service to competing traffic streams, (5) minimize the number of vehicle stops, and (6) minimize delay along the undersaturated elements of the network.

Following comprehensive presentation of the IMP, volume two of the final report concludes with an outline of the next steps in the development that would be required before the policy could be implemented in computerized traffic signal networks.

This research has resulted in a significant advance in our understanding of the phenomena of oversaturated traffic conditions on signalized surface street networks. The researchers have documented the phenomena using comprehensive mathematical and graphical means. Further, a policy to deal with oversaturated conditions has been formulated and described to permit future development and reduction to practice through computerized traffic signal networks.

The final report from this project will not be published in the regular NCHRP report series, but is available on a loan or purchase basis. (See the final page of this document for ordering information.)

Project 3-38(5) FY '88

Effective Utilization of Street Width

Research Agency: Midwest Research Institute
Principal Invest.: Douglas W. Harwood
Effective Date: April 1, 1988
Completion Date: June 30, 1990
Funds: $159,941

New development and changing land use in many urban areas call for increases in street capacity. Frequently, the additional capacity must be provided without an increase in curb-to-curb street width. Lane-width reductions through restriping to provide more lanes, used either alone or in combination with parking prohibitions, median removal, and intersection improvements are among the strategies used to provide additional capacity. Research is needed to document the operational effects of narrower lane widths on congestion reduction and related accident impacts.

The objective of this project is to determine the relationship between capacity and safety for various lane widths and allocations for a given street width. This relationship will be quantified for both street segments and intersections. Such factors as volume-to-capacity ratios, prevailing speeds, vehicle type and volume, alignment quality, service to adjacent property, classification of streets, and environmental factors are among the important operational considerations.

All research has been completed and the final report has been published as NCHRP Report 330, "Effective Utilization of Street Width on Urban Arterials."

Project 3-38(6) FY '88

Cost Sharing for Transportation Improvements Near Major Suburban Employment Centers

Research Agency: Indiana University Foundation
Principal Invest.: Thomas Snyder
Effective Date: May 15, 1988
Completion Date: February 28, 1991
Funds: $125,000

Major employment centers in suburban areas, by their nature, generate vehicle trips that impact surrounding road and signal facilities. Transportation improvements are often required to mitigate impacts, sometimes at considerable distance from the centers. Public agencies are using a variety

of cost-sharing approaches that in certain cases may result in inequities, both among developers and between the developer and the public agency. For instance, a developer who triggers a threshold level for capacity improvements may be burdened with the entire cost. Other developers obtaining approvals before or after the improvement costs have been allocated may not be faced with any of these costs. Inasmuch as an equitable agreement is in the broad public interest, it is important that agencies and developers formulate rational positions and derive fair-share options.

The objective of this research is to provide information to state and local agencies, as well as developers, on (1) how to select the most appropriate cost-sharing approach, (2) specific factors to be considered in allocating costs in each approach, (3) detailed cost-allocation methodologies, and (4) application guidelines. This research will focus on the equitable allocation of the private sector share of transportation improvement costs among individual properties at new or expanding major suburban employment centers.

To meet this objective the following tasks have been accomplished.

Task 1—Review Alternative Cost-Sharing Approaches. Existing approaches to allocating private sector costs will be reviewed, primarily through a literature review.

Task 2—Review Basic Economic Theory. General economic theory and principles will be reviewed for applicability to the equity considerations in determining cost-sharing allocations.

Task 3—Evaluate and Select Alternative Approaches. Based on the results of Tasks 1 and 2, appropriate cost-sharing approaches (e.g., impact fees, assessment districts, negotiated agreements) will be evaluated for application to new or expanding major employment centers and the factors that must be accounted for in implementing each will be identified.

Task 4—Develop Cost-Allocation Methods. For each approach selected in Task 3, an appropriate cost-allocation method will be developed using existing methods to the maximum extent possible. Of particular interest is the use of sound economic theory that provides for the appropriate treatment of costs (i.e., average unit costs, incremental costs, marginal costs, short-term vs. long-term, etc.). Step-by-step procedures for direct application are desired, based on empirical data to the extent possible.

Task 5—Illustrate Alternative Approaches. Use of the alternative cost-sharing approaches and the cost-allocation methods will be illustrated by applying them to at least three representative types of major employment centers (real or hypothetical). The same centers will be used in each case to provide cross comparisons.

Task 6—Develop Guidelines. These guidelines should cover (1) considerations and rationale for the selection of cost-sharing approaches and cost-allocation methods, (2) typical applications, and (3) limitations. The primary audience for the guidelines is at the decision-making level; whereas, the documentation of the approaches and methods should be directed to the analyst.

All research has been completed and the final report has been reviewed by the project panel. The final report will not be published in the regular NCHRP report series but is available on a loan basis. (See final page of this document for ordering information.)

Project 3-38(7) FY '89

Access Management Policies and Guidelines for Activity Centers

Research Agency:	Metro Transportation Group, Inc.	
Principal Invest.:	Frank J. Koepke	
	Herbert S. Levinson	
Effective Date:	May 15, 1989	May 15, 1992
Completion Date:	April 30, 1991	Sept. 30, 1993
Funds:	$124,789	$99,970

The first phase of this project consisted of a broad investigation of the overall concept of access management for activity centers in urban, suburban, and rural settings. The research has resulted in a comprehensive state-of-the-art report, which has been published as *NCHRP Report 348.* The report provides guidelines covering: (1) legal and institutional bases for controlling access, (2) access permit procedures and traffic impact studies, (3) access levels and spacing standards, and (4) design concepts and criteria.

Based on the first phase results, the researchers and the project panel concluded that due to market forces and the availability of land, today's development is in the non-CBD areas of our communities, most often in suburban settings. This led to a recommendation to perform a second, more focused research effort on non-CBD areas.

The primary objectives of the second phase research were to (1) locate roadways to which access management principles had been applied; (2) analyze and evaluate the results of managing access; and (3) summarize study results. Secondary objectives were to prepare: (a) an implementation plan for the research results and (b) an information brochure for elected officials and the public, which explains access management and its many benefits.

The primary objectives of the second phase have been achieved through the preparation of a report, "Case Studies in Access Management." The report documents the results of nine case studies of access management along arterial highways. The locations for the studies were: Dallas, Texas; Atlanta, Georgia; Ft. Lauderdale, Florida; Denver, Colorado; Chicago, Illinois; Detroit, Michigan; Somerset County, New Jersey, and New York City.

The secondary objectives have been achieved through the preparation of a brochure, "Access Management—A Key to Mobility." This document is intended to be a guide for use by communities and public officials and is intended for widespread dissemination to decision-makers. It brings together, in a popularized format, the key findings and rec-

ommendations of the access management research conducted in the previous phase of this project, as supplemented by the case study findings of the second phase. In addition, a draft implementation plan has been prepared. The plan includes an organizational distribution list for the popularized access management guide. Examples of target organizations are the National League of Cities, the National Association of Counties, the Urban Land Institute, the American Planning Association, and the Institute of Transportation Engineers.

All research has been completed. The results of the first phase have been published as *NCHRP Report 348,* "Access Management Guidelines for Activity Centers." (See the last page of this document for ordering information).

A decision on publication of the second phase research results is pending.

Project 3-39 FY '88

Evaluation and Calibration Procedures for Weigh-In-Motion Systems

Research Agency: Texas A&M Research Foundation
Principal Invest.: Dr. Wiley Cunagin
Effective Date: March 1, 1988
Completion Date: December 31, 1993
Funds: $398,500

State highway agencies need accurate truck-weight data for use in planning, design, operations, and maintenance activities related to both highway pavements and bridges. A considerable amount of data is needed to support these activities, as well as for enforcement and highway finance purposes. Further, states are faced with an increasing need for this type of information to implement pavement management systems and to meet the data requirements of the Strategic Highway Research Program.

Various weigh-in-motion systems are available to collect truck data in a more efficient manner than by using conventional weighing methods. A number of states are currently installing these systems and are specifying and conducting independent acceptance and validation procedures. However, nationally recognized procedures for acceptance testing and for on-site calibration of WIM systems do not exist. Such procedures need to be developed and validated by statistically designed field experiments so that WIM users can be confident that WIM-estimated weights will meet specified tolerances for various applications. Widely accepted procedures will also benefit the manufacturers by providing more consistent testing requirements among their customers.

The objective of this research is to develop a procedure(s), covering all WIM system applications, for (1) acceptance testing, (2) on-site calibration, and (3) periodic verification of system performance.

To accomplish this objective, the following tasks will be conducted:

Task 1—Review and summarize the past experience and technical information relating to the evaluation and calibration of WIM systems. Prepare a task report summarizing the existing information's applicability to the objectives of this research and proposing specific procedures for further development in Task 2. Each procedure will include testing under actual traffic conditions; the feasibility of procedures based on simulation of the traffic-induced forces on the transducers will also be specifically addressed, including recommendations for incorporating this simulation into subsequent tasks.

Task 2—Develop recommended procedures for evaluation and calibration of WIM systems. Separate procedures may be needed for acceptance testing, calibration at time of installation at each site, and periodic verification. Factors to be considered include (1) types and applications of WIM equipment, (2) site conditions, (3) traffic mixes, and (4) a statistically valid traffic sample for each site. Provide an interim report including a description of the detailed procedures, a statistically valid experiment design for field testing the procedures, and a design for a pilot test.

Task 3—Pilot test the approved procedures and experiment design through field studies at one or two sites, and makes any needed modifications.

Task 4—Following approval of the revised procedures and experiment design, validate the procedures through field tests.

Task 4A–D—Develop a prototype nondestructive testing device for field testing and calibration of WIM systems. Test the device under different conditions and document the results.

Task 5—Prepare the final report, including documentation that can provide the basis for a nationally accepted test for use by all states.

Research has been completed, but the report will not be published pending the results of a continuation phase.

Project 3-39(2) FY '94

On-Site Evaluation and Calibration Procedures for Weigh-In-Motion Systems

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (21 Months)
Completion Date:
Funds: $250,000

State highway agencies need accurate truck-weight data for use in planning, design, operations, maintenance, and management activities for both pavements and bridges. Weigh-in-motion (WIM) is the process in which the dynamic tire forces of a moving highway vehicle are measured and

then used to estimate wheel, axle, and axle-group loads and gross-vehicle weight. The accuracy of WIM-estimated loads is influenced by site condition, sensor reliability, and other factors. The American Society for Testing and Materials (ASTM) has defined the tolerance (allowable variation from a true value) for WIM-estimated loads and weights for various applications, such as collecting statistical data or screening suspected weight violators from the traffic stream for truck-weight enforcement.

Various WIM systems are available that collect truck data more efficiently than conventional weighing methods. A number of states are currently installing these systems and are specifying and conducting independent acceptance and validation procedures. However, nationally recognized procedures do not exist for on-site evaluation and calibration of WIM systems. Such procedures need to be developed and validated by statistically designed field experiments so that WIM users can be confident that estimated weights will meet tolerances specified for various applications. Widely accepted procedures will also benefit manufacturers by establishing more consistent testing practices by their customers.

An earlier study, NCHRP Project 3-39, *Evaluation and Calibration Procedures for Weigh-in-Motion Systems*, addressed many relevant issues. However, additional research is needed to develop nationally recognized procedures for on-site evaluation and calibration of WIM systems.

The objective of this research is to develop a program for on-site evaluation and calibration of WIM systems. This research will include identifying calibration algorithms to improve WIM system performance and evaluating the feasibility of using test trucks, simulation techniques, and vehicles equipped with automatic vehicle identification (AVI) for on-site calibration of WIM systems.

Accomplishment of this objective will require at least the following tasks. (1) Review evaluation and calibration procedures previously developed by the NCHRP and other research. Define specifications, operational procedures, and test methods for a program for evaluating WIM systems. Within 3 months, submit an interim report presenting the results of this task for review by NCHRP. A revised version that incorporates reviewers' comments shall be submitted. (2) Review and evaluate available WIM calibration algorithms, identify changes to improve WIM system performance, and recommend improved algorithms for at least six vehicle types. These algorithms shall be incorporated in Tasks 3 and 4. (3) Using available data, evaluate existing computer simulation models to determine the feasibility of using test trucks and simulation techniques for on-site evaluation and calibration of WIM systems that meet the requirements for Types I and II as defined in ASTM E 1318, *Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Method.* It is envisioned that selected test trucks along with simulation will be used. Use of vehicles selected at random from the traffic stream is not recommended. (4) Assess the feasibility of evaluating and calibrating WIM systems by continuously monitoring AVI-equipped vehicles and correlate these results with data obtained from reference measuring devices, such as static scales and other WIM systems. Address the feasibility of implementing such calibration techniques in states where AVI facilities are not available. (5) Demonstrate applicability of the findings of Tasks 3 and 4 by conducting a field test that involves two or more contiguous states. Analyze the cost and operational effectiveness of the on-site evaluation and calibration procedures evaluated in these tasks. Based on test results, refine the WIM calibration algorithms developed in Task 2. (6) Submit a final report that documents the entire research effort. The report shall include practical recommendations for on-site evaluation and calibration of WIM systems together with improved calibration algorithms and an implementation plan for moving the results of this research into practice.

Project 3-40 FY '89

Single Point Urban Interchange Design and Operations Analysis

Research Agency:	Texas A&M University Research Foundation
Principal Invest.:	Dr. Carroll J. Messer
Effective Date:	May 1, 1989
Completion Date:	November 30, 1991
Funds:	$250,000

The Single Point Urban Interchange (SPUI) essentially combines two separate diamond ramp intersections into one large at-grade intersection which accommodates all interchanging vehicular movements and the through traffic. Signalization of the one major intersection simplifies coordination on the arterial. It has been reported that SPUIs can significantly increase traffic-carrying capability compared with the conventional diamond interchange.

There are currently numerous uncertainties about the design and operation of SPUIs. These include: wrong-way movement potential; traffic signal, signing, and delineation requirements; sight distance; cost-effectiveness; increased capability to accommodate heavy traffic movements; safety problems; and driver behavior.

The objectives of the research are (1) to document current practice in design and traffic operations at existing SPUIs and (2) to develop and document guidelines for the design, operation, analysis, and cost effectiveness of SPUIs.

To accomplish the objectives, the following tasks are being performed:

Task 1—Determine the state of the art and current practice through a review of the literature and contacts with highway agencies planning, designing, constructing, operating, and maintaining SPUIs.

Task 2—Prepare an interim report which documents the results of Task 1, describes and illustrates key factors in the

design of SPUIs, and lists key strengths and weaknesses experienced to date. The report shall also include recommended refinements of the research plan for the remainder of the project.

Task 3—Develop guidelines to assess the cost effectiveness of SPUIs in comparison with alternative design solutions on a life-cycle basis (right-of-way, pavement, structures, drainage, and function), including first costs, continuing agency costs, user costs, and environmental costs.

Task 4—Develop guidelines for geometric design for use with the AASHTO "Green Book." Guidelines should consider, but not be limited to, the following: turning radii, design speed, free flow movements, channelization design including provision for U-Turns, pedestrian and bicycle accommodations, horizontal and vertical sight distance, capacity, frontage and service roads, and access control.

Task 5—Develop guidelines to analyze the functional performance of SPUI traffic operations throughout its design life (these may be based on existing computer programs). Develop criteria for the optimum placement and operation of traffic control devices. Define safety considerations, including pedestrian and bicycle traffic, and develop recommendations for dealing with the impact of these factors.

Task 6—Prepare a final report, documenting the research and presenting the findings, with emphasis on the user guidelines for those highway agencies contemplating selection, design, construction, operations, and maintenance of SPUIs.

All work has been completed and the final report has been published as *NCRHP Report 340,* "Single Point Urban Interchange Design and Operations Analysis." (See last page of this document for ordering information.)

Project 3-41 FY '90

Procedure for Determining Work Zone Speed Limits

Research Agency: Graham-Migletz Enterprises, Inc.
Principal Invest.: James Migletz
Effective Date: November 15, 1989
Completion Date: May 31, 1993
Funds: $200,000

A recent poll of the members of the AASHTO Highway Subcommittee on Traffic Engineering confirmed that the nationwide safety problem in work zones is being aggravated by the lack of uniform guidelines for determining speed limits. Inconsistencies in the methods used to determine work zone speed limits, noncompliance with the posted speed limit by motorists, and the growing practice of setting work zone speed limits through administrative decisions without benefit of an engineering study are major contributors to this safety problem.

While the national *Manual on Uniform Traffic Control Devices* (MUTCD) presents uniform guidelines for determining the speed limit on roads free of work activities, it fails to provide a procedure for determining work zone speed limits. At their 1988 joint summer meeting in Jackson, Wyoming, the AASHTO Highway Subcommittee on Traffic Engineering and the Construction and Maintenance Technical Committee of the National Committee on Uniform Traffic Control Devices unanimously concurred that research is urgently needed to establish a procedure for determining work zone speed limits.

The objective of this project is to develop a uniform procedure for determining work zone speed limits. This procedure should be usable during both the design and construction phases of a roadway construction project and should be developed to accommodate, to the maximum extent possible, the often divergent interests of motorists, workers, and pedestrians.

This project shall consist of at least the following tasks:

Task 1. Using an extensive literature search, interviews with knowledgeable individuals, and other appropriate survey techniques, identify, from a broad spectrum of state and local agencies, current procedures and actual practices related to the determination of speed limits both generally and in work zones, and assess motorist compliance with speed limits in work zones.

Task 2. Based on the results of Task 1, develop a data collection and analysis plan to accomplish the project objective. Factors to be included in this plan shall include but not be limited to: (a) identification of work zone characteristics that should be included in a procedure for determining speed limits; (b) formulation of one or more potential procedures for determining work zone speed limits; (c) description of how the most effective procedure for determining work zone speed limits will be selected; and (d) identification of data collection sites. The data collection sites shall include a sampling by geographic region, by level of development (urban, suburban, rural), by roadway classification (e.g., freeway, expressway, divided arterial, undivided arterial), and by type and duration of work zone activity.

Task 3. Prepare an interim report documenting the research completed in Tasks 1 and 2. Submit the interim report for review by the NCHRP project panel. Soon after distribution of the interim report, a meeting between the research team and the NCHRP project panel will be scheduled for the purpose of providing panel members the opportunity to interact with the researchers in a detailed discussion on the contents of the interim report. NCHRP approval of the interim report will be required before proceeding with Task 4.

Task 4. Implement the data collection and analysis plan approved by the panel in Task 3. The final procedure for determining work zone speed limits shall be readily usable and easily applicable to most work zones.

Task 5. Prepare a final report documenting the research effort. It should contain language consistent with the format of the MUTCD to facilitate adoption of the recommended procedure for determining work zone speed limits into Part

VI of the MUTCD. It should also contain an applications-oriented user's manual with a diversity of examples describing the use of the recommended procedure. The user's manual must be capable of serving as a stand-alone document. The researchers shall make presentations to the AASHTO Highway Traffic Engineering Subcommittee and National Committee on Uniform Traffic Control Devices describing the research effort and the recommended procedure for determining work zone speed limits.

The research has been completed and will be summarized in Research Results Digest 192. A continuation phase has been initiated as Project 3-41(2).

Project 3-41(2) FY '94

Effectiveness & Implementability of Procedures for Work Zone Speed Limits

Research Agency: Graham-Migletz Enterprises, Inc.
Principal Invest.:
Effective Date:
Completion Date:
Funds: $200,000

NCHRP Project 3-41 entitled "Procedure for Work Zone Speed Limits" developed a new procedure for setting work zone speed limits based on engineering factors associated with particular work zones. In general, the procedure discourages reductions in the speed limit in work zones when no active work is underway or when all work is on the shoulder or roadside. The procedure suggests that when work is underway in or near the traveled way, a reduction of 10 mph in the work zone speed limit may be justified. Other engineering factors, such as the presence of unprotected workers near the traveled way for extended periods, may also justify a 10-mph speed limit reduction under the procedure. Finally, where physical restrictions require the use of roadway geometrics that require lower design speeds, a speed limit reduction to the design speed of the geometrics is justified, even if this requires a reduction in speed limit larger than 10 mph. While the previous research analyzed traffic operations and safety in work zones to develop the procedure, there is a need to evaluate its effectiveness in actual applications and on a wider scale. These applications need to be assessed in the context of the traffic control treatments used and the range of roadway and environmental situations that are encountered. There is a need to evaluate the potential influence of work zone speed control treatments to provide a sounder basis for the application of the procedure. It is also necessary to assess the implementability of the procedure to determine how well it meets the full range of needs faced by highway agencies and to identify institutional, legal, and practical constraints to its use. These evaluations are expected to indicate were further refinements to the procedure are necessary. The objectives of the research are: (1) to assess the implementatbility of the procedure for setting work zonenting it. Determine the adequacy of its range of its applicabilors and design practices; (2) to document the effect on vehicle speeds of work zone speed limits established with the new procedure; (3) to make recommendations to refine and extend the procedure as appropriate, and (4) to prepare guidelines to facilitate the implementation of the procedure.

To accomplish these objectives, the following tasks are envisioned:

Task 1. Contact transportation agencies to solicit feedback on the perceived feasibility of the procedure. Structure the contacts to determine highway agency experience with increasing compliance with work zone speed limits and addressing special situations such as night work or during transitions between major phases of the work activity (i.e., shifting from a right-lane closure to a left-lane closure). Visit selected states to observe their processes for setting work zone speed limits and selecting traffic control methods.

Task 2. Identify at least 4 state highway agencies willing to participate in field tests of the new work zone speed limit procedure. The participating states should be located in different regions of the United States and should have a variety of current procedures for setting work zone speed limits. Working with each participating state agency, develop a plan for how that agency will implement the new work zone speed limit procedure for selected projects over an entire construction season. The plan should describe the methods that would be used to measure changes in speed compliance. The plan should include a scheme to classify the selected projects by highway type, work zone traffic control treatments, traffic volumes, and other factors as appropriate.

Task 3. Prepare an interim report that summarizes the findings of the agency contacts and describes the plan for implementation of the new procedure for setting work zone speed limits and the associated field evaluations. Meet with the project panel to review the report and finalize plans for the field tests.

Task 4. Implement the procedure in the selected agencies documenting the methods used and the difficulties encountered in accordance with the approved plan. In each participating state, the research team will provide assistance in implementing the procedure as necessary.

Task 5. Conduct evaluations of the work zone speed compliance in accordance with the plan approved in Task 3. At a minimum, collect traffic speed data upstream of and within selected work zones to document the level of motorist compliance with the prescribed speed limits. Document the data gathered in this effort for possible future analysis.

Task 6. Based on the results of Tasks 4 and 5, recommend appropriate modifications to the work zone speed limit procedure based on initial highway agency experience in implementing it. Determine the adequacy of its range of its applicability and recommend special procedures or adjustments to extend applicability of the procedure. Prepare guidelines

to facilitate the implementation of procedure by highway agencies.

Task 7. Prepare a final report that documents the findings of the research and presents the work zone speed limit procedure and guidelines for its implementation in a convenient form for application by highway agencies.

Project 3-42 FY '91

Determination of Stopping Sight Distances

Research Agency:	Texas A & M Research Foundation
Principal Invest.:	Dr. Daniel B. Fambro
Effective Date:	May 1, 1991
Completion Date:	May 1, 1994
Funds:	$500,000

The current procedures for determining stopping sight distance (SSD) are intended to allow a normally alert passenger-car driver, traveling at or near the highway design speed on wet pavement, to react and bring the vehicle to a stop before striking a stationary object in the road. The basic model for this situation was formalized by the American Association of State Highway and Transportation Officials (AASHTO) in 1940, and over the past 50 years, the model's parameters have been modified to account for changes in the vehicle-driver-roadway system. (See *A Policy on Geometric Design of Highways and Streets,* AASHTO, 1984.) The 1984 *NCHRP Report 270,* "Parameters Affecting Stopping Sight Distances," raised concerns about the model's validity as well as the appropriateness of certain parameter values used to calculate SSD. Subsequent research has revealed additional concerns about the validity of the model. Examples of such research are cited in *Transportation Research Record 1208,* "Highway Sight Distance Design Issues," 1989.

Stopping sight distance influences the geometric design of streets and highways, most notably horizontal and vertical alignment; these design features add to the cost of new highway construction, and can dramatically increase the cost of major roadway reconstruction. Use of decreased pavement-tire friction values, and lower eye and object heights (as recommended by *NCHRP Report 270*), in the current AASHTO SSD model would lengthen the desirable SSD. State highway agencies report that changes would create serious problems and would substantially increase costs without demonstrated safety benefits. Some older research studies, attempting to relate SSD to safety, appear to be inconclusive and inconsistent. Research results have suggested that the current SSD model does not properly reflect the actual driving environment. However, some recent studies have shown that safety is apparently not compromised when actual SSD's are marginally less than current standards. Considering the high construction costs associated with longer SSD's and the uncertain safety benefits resulting therefrom, State highway officials have concluded that a substantial research effort is needed to evaluate available information, add to it, and recommend improvements to current practice.

The objective of this research is to evaluate, on the basis of the impact on vertical and horizontal curve design, the current AASHTO methodology and alternative approaches to establishing stopping sight distance. Based on a review of current and alternative practices, updated representative vehicle-performance characteristics, roadway and pavement characteristics, and driver-behavior data, recommended design procedures will be developed for specific applications. Issues such as the variability of the roadway facility, cost-safety-effectiveness of the design, and ease of applying the SSD model shall be taken into account.

To accomplish this objective, the following tasks will be conducted:

Phase I:

Task 1. Conduct a review of pertinent literature and research in progress on, as a minimum, the following topics:

a. Driver-Vehicle-Roadway Relationships—Identify and analyze the state of the art for:

- Wet pavement (concrete and asphalt) braking tests at high speeds.
- Typical driver braking control efficiency at high speeds.
- Locked wheel braking versus controlled stops.
- Peak friction versus slide friction.
- Effects of anti-lock brakes, including driver-behavior adaptations.
- Truck braking characteristics, including on grades and horizontal/vertical curves.
- Diminished truck braking capabilities caused by inadequate maintenance.
- Pavement friction variations in a typical state.
- Object height and recognition of top of object.
- Eye height.
- Perception-reaction time, including elderly drivers.
- Distinction between design and operating speeds.
- Headlight limits.

b. Accident Data and Related Information—Identify previous studies relating SSD and accident rates, including historical accident data, simulation, and field studies. Examine the tort liability exposure of highway agencies caused by limited SSD, and review cost-safety effectiveness methodologies developed for other highway design and safety situations and their applicability to the SSD issue.

c. Alternative SSD models—Identify alternative methodologies including those considered or adopted by other countries, under development by researchers, or suggested by the literature.

Task 2. Assess the adequacy and accessibility of existing local, state, and national databases to provide pertinent information on, at a minimum: (a) the national vehicle fleet including percentage composition, braking characteristics, ground clearance, and typical driver eye position within the vehicle, (b) roadway pavement characteristics including

friction values for roadways of various composition and classification, (c) measures of effectiveness of changes in SSD's, and (d) accident experience to assess the impact of various stopping sight distance models.

Task 3. Accomplish a critical analysis of AASHTO and other promising SSD models including the parameters required in each model. The alternative models may be either suggested in the literature or developed in the course of the research. The advantages and disadvantages of each model should be thoroughly documented, including model practicality, complexity, and representativeness of the driver-vehicle-highway system. Any deficiencies in the available data needed to accurately assess the model's impact, validity, or practicality should be carefully documented. Finally, a fully supported recommendation should be made concerning the retention of the current AASHTO SSD model, or the potential implementation of a refined AASHTO SSD model(s) or alternative SSD model(s).

Task 4. Prepare an interim report in two parts. The first part will document the results of Tasks 1, 2 and 3. A second part of the report will be a detailed revision of the Phase II portion of the original work plan which describes the rationale, methods, required data, data collection plan, schedule, budget, and special facilities, equipment or arrangements required to perform Tasks 5, 6 and 7. The purpose of these tasks is to validate and refine the models recommended in Task 3. Immediately following review by the project panel, the research agency will be required to make a presentation, to the project panel, in Washington, D.C. Work on Tasks 5, 6 and 7 will not begin until authorized by NCHRP.

Phase II:

Task 5. Collect data and conduct field tests, where necessary, to implement the data collection plan approved by NCHRP in Task 4.

Task 6. Validate recommended SSD model(s) and determine the credibility, ease of use, and cost and benefit impact of applying the recommended SSD model(s). As a minimum the validation shall include: (a) a sensitivity analysis of the parameters used in the recommended model(s), (b) a comparison and assessment of the SSD values obtained from the new or revised model(s) with the existing AASHTO SSD model if necessary, (c) an evaluation of the consistency of use by a sample of individuals when presented with the same design situation, (d) an assessment of the impacts in terms of costs and benefits, and (e) the effect on tort liability of any longer SSDs as related to both design of new facilities and the need for making changes to existing sites. Revise model(s) as needed and develop final recommendations to AASHTO on the basis of the findings of Task 6.

Task 7. Prepare final report. The report will cover the entire project. All data necessary to use the model(s) recommended in Task 6 should be included in the report and, if appropriate, provided on separate 3.25-inch diskettes. Following review and comment by the project panel, the research agency will be expected to make a presentation on the project findings to the project panel in Washington, D.C., within 30 days of receipt of the comments. Subject to review and approval by the project panel, the research agency will be required to make a presentation on the project results and recommendations to the AASHTO Task Force on Geometric Design.

Research on Tasks 1 through 5 has been completed, and the Phase I report has been reviewed and approved by the project panel. Work is proceeding on Task 6.

Project 3-43 FY '91

Use of Shoulders and Narrow Lanes to Increase Freeway Capacity

Research Agency: JHK & Associates
Principal Invest.: James E. Curren
Effective Date: January 15, 1991
Completion Date: April 15, 1994
Funds: $300,000

Increasing traffic congestion, coupled with limited resources to build new freeways, has created a need for additional capacity on existing freeways. Frequently, this can be accomplished by adding lanes through the use of shoulders both as a stand-alone strategy or in conjunction with reduced lane widths. This approach offers a lower cost alternative, with minimal community impacts and can be implemented more quickly than widening the freeway to add lanes. Projects of this type have been implemented in several states and are proposed in others.

The objectives of this project are (1) to investigate the trade-offs among facility design, traffic performance, safety, enforcement, system operations and maintenance impacts; (2) to develop a methodology for the evaluation of alternative applications; and (3) to provide recommended design guidelines for these strategies.

Task 1. Conduct a search of published and unpublished literature on past, existing, and proposed projects involving shoulder use and reduced lane widths.

Task 2. Develop and conduct a survey to (1) determine past, present, and proposed projects involving the use of shoulders and reduced lane widths to increase capacity; (2) identify the rationale for and the purpose of each application; (3) document operating experience; (4) identify types of shoulder use, lane-width-reduction strategies, and the resulting lane configuration and use; (5) determine data availability; and (6) identify key measures-of-effectiveness that have been or can be used to evaluate these strategies.

Task 3. Develop a research plan for determining the effects of shoulder use and reduced lane width strategies on facility design, traffic performance, safety, enforcement, system operations, and maintenance over a wide range of conditions.

Task 4. Submit an interim report that (1) provides a summary of the literature search; (2) provides a synopsis of the

survey results; (3) recommends the range of strategies to be studied, data to be obtained, and measures-ofeffectiveness to be used in evaluating alternatives; and (4) presents a detailed research plan and revised budget required to complete the research.

Task 5. Carry out the approved research plan.

Task 6. Develop a detailed methodology to allow the user to evaluate potential applications of shoulder use and reduced lane width strategies. The methodology should include consideration of the trade-offs among facility design, traffic performance, safety, enforcement, system operations, and maintenance issues.

Task 7. Develop recommendations and design guidelines for implementation and operation of shoulder-use and reduced lane-width projects.

Task 8. Assess the applicability of the research results to major freeway reconstruction projects, shoulder-use and reduced lane-width projects on nonfreeway facilities, and other appropriate extensions of the research.

Task 9. Prepare a final report. The main body of the report shall document the results of the study. User guides for applying the results of Tasks 6 and 7 shall be included as stand-alone appendixes within the final report.

All research has been completed and the final report is being reviewed by the project panel.

Project 3-44 FY '92

Improved Traffic Control Device Design and Placement to Aid the Older Driver

Research Agency: Michigan State University
Principal Invest.: Dr. Richard Lyles
Effective Date: April 15, 1992
Completion Date: October 15, 1994
Funds: $350,000

In the future, a larger percentage of drivers will be older citizens, with age-related diminishing performance capabilities resulting from changes in sensory, perceptual, cognitive, and psychomotor functions. General improvements in the design, use, and application of traffic control devices are believed to be necessary to accommodate the changing driving population. Although recent studies have identified such improvements to accommodate diminished driving performance, there has been only limited field testing of them. The FHWA study entitled "Traffic Control Design Elements for Accommodating Drivers with Diminished Capacity" found through lab studies that improved sign displays and redundancy may be beneficial to the older driver. In the case of urban intersections, it was shown that redundant upstream signing for left-turn signals and special sign displays facilitate rapid and appropriate decision-making.

The primary objective of this research is to determine which traffic control device improvements enhance driver performance with particular emphasis on older drivers. The research is intended to define the characteristics of the older driver that affect the design and application of traffic control devices, determine which traffic control device characteristics or applications play a major role in older driver performance in terms of safety, mobility, and traffic operations, conduct the tests necessary to confirm the effectiveness of improvements to traffic control devices, and translate the research findings into practical recommendations for improvements in traffic control device design, use, and application. This research is intended to consider all traffic control devices as used at intersections, interchanges, and roadway sections on roadways of all functional classifications in urban and rural environments. Traffic control device effectiveness should be assessed for day and night conditions and under varying traffic scenarios.

The tasks associated with this research will include: (1) Conduct a literature search and review relevant, on-going research to identify potential improvements in traffic control devices (i.e., highway signs, pavement markings, and traffic signals) and their applicability to the specific needs of older drivers. This task should produce a summary of the major efforts and practices being used by state agencies. (2) Define analytically the characteristics of the older driver that should be considered in the design, use, and application of traffic control devices. (3) Identify those driving and roadway situations that create problems for older drivers where traffic control devices offer potential for enhancing the safety and mobility of older drivers. (5) Develop a research plan to evaluate the effectiveness of the highest ranked improvements. The research plan shall include experiments that assess driver performance and/ or device effectiveness in dynamic, multi-task driving situations. (6) Prepare an interim report summarizing the efforts and findings of Tasks 1 through 5 including a prioritized list of recommendations for the improvements to be studied. An interim meeting will be convened with the project panel and the contractor to review recommended improvements for further study. (7) Execute the research plan approved in Task 6. Implement procedures to ensure the integrity of data gathered. Evaluate the data gathered in the field studies and document the findings of the various analyses undertaken. (8) Recommend improved procedures for design and placement of traffic control devices to aid the older driver. Assess the costs and benefits associated improvements to individual device installations and with implementation systemwide. The contractor will present the findings of the study to a professional group (e.g., AASHTO Traffic Engineering Subcommittee, National Committee on Uniform Traffic Control Devices) as designated by the panel to obtain additional feedback. (9) Prepare a Final Report, which documents the efforts and findings of this research.

The panel approved the interim report and research is proceeding.

Project 3-45 FY '93

Speed-Flow Relationships for Basic Freeway Segments

Research Agency: JHK & Assoc
Principal Invest.: James M. Schoen
Effective Date: November 1, 1992
Completion Date: April 30, 1995
Funds: $350,000

A more definitive understanding of speed-flow relationships and capacity on freeways is needed. The material in Chapter 3, "Basic Freeway Segments," of the *1985 Highway Capacity Manual* (HCM) is based on sparse databases and on information no longer current. Basic freeway flow characteristics and the impact of heavy vehicles and restricted lane/shoulder widths have not been comprehensively studied since the early 1960s. In addition, a number of other factors that may affect speed-flow relationships are either ignored or are not well specified in the HCM. These include driver experience with congested freeways (which may be reflected in city size, changing relationships over the day or week, and the average duration of daily congestion), urban versus rural settings, horizontal and vertical geometry, the presence of ramp metering, day-night differences, and others.

The recently completed NCHRP Project 3-33, Capacity and Level of Service Procedures for Multilane Rural and Suburban Highways, has recommended an increase in multilane highway capacity, from the 1800 passenger cars per hour per lane (pcphpl) indicated in the 1985 HCM, to 2200 pcphpl. This is greater than the *freeway* capacity specified in the 1985 HCM. (Project 3-33 has resulted in a new Chapter 7 for the HCM that is in press.) The Project 3-33 results imply that freeway capacity as specified in the HCM should be increased to at least 2200 pcphpl, and that revisions to the speed-flow relationships in Chapter 3 of the HCM should be investigated to reflect the likely changes in capacity at various free-flow speeds.

The objective of this research is to revise material on speed-flow relationships for basic freeway segments in order to update Chapter 3 of the HCM. Accomplishment of this objective will require at least the following tasks:

Phase I—(1) Survey freeway management agencies to determine the availability of data related to speed-flow relationships. Identify, review, and synthesize the results of ongoing or completed freeway studies to gain a better understanding of capacity concepts and speed-flow relationships for basic freeway segments. The synthesis should cover not only the characteristics of the speed-flow relationships that are generally known and accepted, but also the characteristics that remain open to question. (2) Based on the results of Task 1, develop an overall framework that describes speed-flow relationships, with specific focus on operations at or near capacity as well as during congested (level of service F) conditions. This effort should include identification of those key geometric, operational, and environmental factors that are believed to influence capacity and the speed-flow relationships on basic freeway segments. Such factors may include, but are not necessarily limited to, variances associated with driver experience and its relationship to city location or size, presence of ramp metering systems, and diurnal effects. The effort should also include a review of existing Chapter 3 adjustment factors and their values. The results of Task 2 will form the basis for prioritization and collection of data. (3) Prepare a detailed plan for collecting data and performing analytical studies to quantify the speed-flow relationships and other factors identified in Task 2. The plan should include priority groupings of those data elements that are: (a) credible, available from others, and of recent vintage, (b) obtainable given available funding, and (c) desirable given additional funding or those that should be collected by others in subsequent research. The plan shall identify all variables to be studied, the expected sample size, and data-collection costs. The resulting database should include a variety of geographical regions. The plan shall specify quality-control measures and anticipated methods of analyzing the data. The use of existing automated data-collection techniques is acceptable. The development of such techniques, however, is not within the scope of this project. (4) Prepare an interim report, including the results of Tasks 1 through 3 and an updated budget for Phase II. The researchers shall meet with the NCHRP project panel and selected members of the TRB Highway Capacity Committee for review and approval of the Phase I report before proceeding to Phase II. It is anticipated that 60 days will be required between submission and approval of the Phase I report.

Phase II—(5) Collect data according to the plan approved in Task 4. Document the procedures in sufficient detail to allow supplementary data collection by others later. (6) Analyze the data collected in Task 5 and develop updated speed-flow relationships and recommended adjustment factors and their values in accordance with the Task 2 framework and the Task 3 study plan. The results of this analysis will form the basis for: (a) the suggested revisions to Chapter 3 of the HCM, and (b) a technical memorandum on the implications of a revised Chapter 3 on Chapters 4 through 6. (7) Prepare and submit a final report, documenting the entire research effort. The final report should include: (1) a recommended draft of a revised Chapter 3 of the HCM, clearly showing deletions and new material, (2) a commentary on Chapter 3 as revised, (3) the memorandum on the implications for Chapters 4 through 6, and (4) an Appendix setting out recommended data-collection priorities and analysis procedures for use by others in subsequent research. The final report will be sent to the TRB Highway Capacity Committee for review and comment as part of the NCHRP project panel approval process.

Phase I has been completed and the interim report has been reviewed by the project panel and revised by the researchers. A substantial portion of the Phase II data collection has been completed.

The interim report is available on a loan or purchase basis. See last page of this document for ordering information.

Project 3-46 FY '93

Capacity and Level of Service at Unsignalized Intersections

Research Agency: University of Idaho
Principal Invest.: Dr. Michael D. Kyte
Effective Date: January 1, 1993
Completion Date: June 30, 1995
Funds: $400,000

A more definitive understanding of capacity and level of service (LOS) at unsignalized intersections is needed to properly analyze their performance. For example, one of the primary problems with Chapter 10 of the *1985 Highway Capacity Manual* (HCM) is that the analysis procedures presented are not based on delay and therefore, are not compatible with the capacity analysis procedures for signalized intersections in Chapter 9. Because the definition of level of service in terms of delay has gained such wide acceptance, Chapter 10 needs revision to include these measures. Further, the revised procedures should be consistent with the new requirements of the Intermodal Surface Transportation Efficiency Act of 1991 and Federal Clean Air Act Amendments of 1990. Finally, there is a growing desire among users to explore the use of simulation models, which can be used in conjunction with, or possibly to replace, existing capacity analysis procedures.

Six major deficiencies of Chapter 10 have been identified: (1) the two-way STOP-controlled (TWSC) method is based on an outdated 1972 West German method, (2) no formal procedure exists for the analysis of all-way STOP-controlled (AWSC) intersections, (3) the use of reserve capacity as a Measure of Effectiveness (MOE) is not consistent with the delay measure used for signalized intersections, (4) the performance of unsignalized intersections within a coordinated signal system is not adequately addressed, (5) no planning or design procedure is presented, and (6) the methodology fails to provide guidance regarding the use of unsignalized versus signalized control at a given intersection [including correlation with warrant criteria contained in the Manual on Uniform Traffic Control Devices (MUTCD)].

The objectives of this research are (1) to develop and validate capacity analysis procedures for AWSC and TWSC intersections that can replace the existing procedures in HCM Chapter 10 and (2) to correlate these capacity procedures with the MUTCD warrants for installation of signals and AWSC to provide consistency between the HCM and the MUTCD.

The completed project will produce two technical reports, a draft of Chapter 10, and a replacement for the current Highway Capacity Software (HCS) module. The project will be divided into two phases and should include at least the following tasks:

Phase I—(1) Conduct a literature review to evaluate domestic and international capacity analysis procedures, both analytical and simulation based, and assess unsignalized intersection data-collection procedures. This literature review will form the basis for the selection of the analytical procedures and simulation models in Task 3 and for the data-collection procedures to be developed in Task 4. Identify operational and geometric characteristics that are of critical importance for both TWSC and AWSC intersections, including, but not limited to, number of lanes and lane usage, and, for TWSC intersections, approach speed on the main street, and distance to signalized intersections. Consider other characteristics such as pedestrian volumes, traffic composition, area type, intersection geometry, and the presence of a coordinated signal system. (2) Conduct a user survey to determine: (a) where the existing procedures have been applied, (b) where the user community would like to apply the new procedures, and (c) the extent to which the HCM YIELD-controlled procedures are used. The survey questionnaire and distribution list shall be submitted to the NCHRP panel for review and approval before distribution. (3) Based on the results of Tasks 1 and 2, propose AWSC and TWSC analytical capacity-analysis procedures. Compare the proposed procedures with those identified in Task 1. Evaluate existing simulation models and recommend a model(s) that could be used in conjunction with, or possibly as a replacement for, analytical capacity-analysis procedures. One of the MOEs produced by the selected procedures or models must be average stopped delay per vehicle consistent with HCM Chapter 9. Consider other MOEs, such as queue length and move-up time, that can be used to derive fuel consumption, air quality, and cost-related measures. Eliminate those characteristics and relationships that demonstrate no significant influence on capacity or level of service. Base the proposed procedures on a systematic approach that represents a rational and logical application of the principles of interrupted traffic flow. (4) Prepare a field data-collection and analysis plan to quantify the volume/delay relationships as they relate to the characteristics identified in Task 1. Investigate the existence of current usable field data before preparing the plan. Data-collection sites should represent a variety of nationwide geographical locations, traffic demands, geometrics, and other key characteristics. The plan shall identify the expected level of precision, sample size, specific costs, and priorities for each data-collection category. A method for early identification of problems that may arise in the data collection and analysis shall also be included. The use of automated data-collection techniques, such as video imaging, is allowed, but the development of such techniques is not an objective of this study. (5) Submit a technical memorandum for review by the NCHRP panel before proceeding with Task 6. The technical memorandum shall discuss the proposed AWSC and TWSC procedures and describe the site-selection, data-collection, and analysis

plan for a pilot study. (6) Conduct a pilot study using a sufficient number of representative sites for each application (TWSC and AWSC) so that the data-collection and analysis procedures developed in Task 4 can be validated. (7) Prepare a Phase I report including: (1) a revision of the data-collection and analysis procedures based on the results of the pilot study, (2) the revised data-collection schedule, and (3) a revised budget for Phase II. The data-collection plan should identify the number of sites necessary to collect a statistically significant sample for each application (TWSC and AWSC) and a combination of operational and geometric conditions. The plan should also address quality control issues. The researchers shall meet with the NCHRP panel and appropriate members of TRB's Highway Capacity Committee for review and approval of the Phase I report before proceeding to Phase II. It is anticipated that a 60-day period will be required for review and approval of the Phase I report.

Phase II—(8) Collect field data according to the approved plan. Data shall be collected under good weather conditions and during daylight hours. Use the data collected to calibrate the computational procedures. (9) Using the field data collected in Task 8, modify the procedures as appropriate. The format and style of the procedures should be consistent with other analysis procedures contained in the HCM. (10) Examine the traffic simulation model(s) recommended for use in Task 3 and determine if they can be calibrated to reflect the data observed in the field and if they agree with the predictions provided by the analytical procedures from Task 9. If modification of existing models or development of new simulation models is determined to be necessary, this additional work is not within the scope of this project. (11) Assess the points of compatibility and conflict between the MUTCD warrant analyses and the unsignalized intersection capacity analyses. Provide recommendations that would eliminate these conflicts. (12) Prepare a new version of the HCM Chapter 10, "Unsignalized Intersections," containing the improved analysis procedures. This material shall follow the style of the 1985 HCM and shall be suitable for insertion into the HCM. Figures, tables, photographs, and worksheets shall be provided in final camera-ready form. (13) Prepare new software that incorporates the procedures of this project into the HCS module for Unsignalized Intersections, which is currently distributed and maintained by the McTrans Center. The new module shall use the language, software standards, and "look and feel" of the HCS. Fully documented source code and user documentation shall be provided. The new version of the HCM Chapter 10 produced in Task 12, and the new version of the HCS produced in this task will be reviewed and approved by the NCHRP project panel. (14) Prepare a detailed final report describing the form, content, and rationale for the recommended capacity analysis procedures, and, if appropriate, simulation-model based procedures. The levels of precision and sensitivity of the procedures shall be documented. The report shall include a list of incompatibilities between the new procedures and HCM Chapters 9, "Signalized Intersections," and 11, "Urban and Suburban Arterials." The report will be subject to review and approval by the NCHRP project panel and appropriate members of TRB's Highway Capacity Committee.

All work on Tasks 1–6 has been completed and the interim report on Phase I is being reviewed by the project panel.

Project 3-47 FY '94

Capacity Analysis of Interchange Ramp Terminals

Research Agency: Texas A&M Research Foundation
Principal Invest.: Dr. Carroll Messer
Effective Date: January 15, 1994
Completion Date: July 15, 1996
Funds: $400,000

One of the most critical elements in the highway system is the grade-separated interchange. Within freeway/arterial and arterial/arterial interchanges, signalized ramp terminals on the arterial crossroad are often the key operational elements. Unfortunately, the interchange facility, which is a very costly link in the network, often performs poorly having numerous conflict points, high traffic demands, changes in speeds, and high-volume turning movements.

Conflicts between through movements are typically grade separated, while other movements are served at-grade. To improve major road operations, many maneuvers that tend to generate conflicts and delays (such as stopping, turning, and weaving) are designed to occur on the minor road. However, on the minor road, the relatively close spacing of the ramp terminals combined with the high volume of interchanging traffic tends to cause operational problems. These problems include long delays, poor minor-road progression, long queues, and, in some cases, queue spillback between adjacent ramp intersections. Spillbacks from the major road onto the "local" street, or from the off-ramp onto the major road, are related problems.

Resolution of the aforementioned problems is critical to the safety and efficiency of the corridor. Moreover, Intelligent Vehicle Highway System (IVHS) technologies are dependent on the ability to divert traffic, in real time, around congested areas. If corridor interchanges are operating inefficiently, the potential for diversion is diminished, and the benefits of IVHS may be reduced.

Chapters 9 and 11 of the *1985 Highway Capacity Manual* (HCM) cover signalized intersections and arterial streets, respectively. Neither of these chapters, nor others in the HCM, address two important considerations: (1) signal coordination needs and progression characteristics of signalized ramp terminals and other closely spaced signalized intersections, and (2) queue spillback on the ramps and onto the crossroad. Thus, a methodology is needed to analyze signalized ramp terminals and adjacent intersections simultaneously. This methodology should be capable of addressing

both coordinated pretimed and coordinated actuated signal systems.

The objective of this researchis to develop and validate an appropriate methodology for determining capacity and level of service (LOS) at signalized ramp terminals, including adjacent closely spaced arterial intersections. The methodology should describe and quantify appropriate measures of interchange performance. A wide range of interchange configurations that include one or more traffic signals at the ramp terminals should be specifically addressed. Unsignalized at-grade movements, such as right turns, and arterial weaving between intersections also need to be considered.

This research will (1) evaluate the state of the art in operational analysis of signalized ramp terminals, including adjacent closely spaced intersections; (2) develop and test a new methodology for analyzing capacity and LOS at these locations, and (3) validate the proposed methodology. The research results may form a new chapter in the HCM and should be compatible with existing chapters.

The project will be divided into two phases and will include the following tasks:

PHASE I. *Task 1.* Conduct a state-of-the-art review to evaluate domestic and international experience on capacity and LOS analysis of the following, as a minimum: Interchange Ramp Terminals, Signalized Intersections, Closely Spaced Signals, Pedestrian Movements at Interchanges, Interchange Geometric Design, Arterial Weaving, Queue Spillback and Its Effect on Saturation Flow.

Task 2. Identify appropriate measures of effectiveness (MOEs) for the analysis of interchange ramp terminals. Some of the MOEs to be considered include delay, queue spillback, progression, stops, throughput, volume/capacity (*v/c*) ratio, speed, and travel time. Recommend MOEs for use in the methodology to be developed in subsequent tasks and consider their compatibility with other chapters of the HCM, particularly Chapters 9 and 11.

Task 3. Assess the applicability and validity of existing models for analysis, simulation, and optimization of interchange ramp terminals and at least one closely spaced signal on either side of the interchange. Identify the strengths and weaknesses of each model, especially as related to the MOEs identified in Task 2. Determine whether existing capacity procedures for signalized intersections adequately address interchanges such as Single Point Urban Interchanges (SPUIs) having only one signal on the arterial crossroad, or whether such interchanges need to be addressed by the proposed methodology.

Task 4. Formulate several alternative methodologies, either new or revisions of those existing, to determine the recommended MOEs and to address the weaknesses identified in Task 3. Both analytical and simulation approaches should be explored. Assess the alternative methodologies and recommend the most promising methodologies for further development in subsequent tasks. Investigate the impacts of each alternative methodology on the HCM. Identify the type of software that may be needed to implement each alternative methodology.

Task 5. Prepare an interim report presenting the results of Tasks 1–4, a preliminary data-collection and analysis plan for Task 6, proposed criteria for evaluating alternative methodologies as part of Task 7, and an updated work plan for all remaining tasks. Discuss this report at a meeting with the NCHRP panel and selected members of the TRB Highway Capacity Committee.

PHASE II. *Task 6.* Collect and analyze data according to the approved plan. Field data should be collected to calibrate and validate the alternative methodologies. Field sites should include a representative range of geographical, design, and operational conditions. The data should be reduced and analyzed. A portion of the field data should be set aside for later validation of the methodology selected in Task 7.

Task 7. Evaluate the alternative methodologies using field data. Select, refine, validate, and document the most promising methodology using the set-aside data.

Task 8. Prepare a draft final report that contains the research results, a detailed explanation of the rationale for the selection of the recommended methodology, and a description of the software needed to implement the methodology. The report shall also recommend whether the proposed HCM material should appear as a new chapter or be incorporated into existing chapters. The final report shall also include an executive summary, which outlines the proposed changes to the HCM, and explains how they may affect other chapters.

Project 3-48 FY '94

Capacity Analysis for Actuated Intersections

Research Agency:	University of Florida Research Foundation
Principal Invest.:	Prof. Kenneth G. Courage
Effective Date:	December 1, 1993
Completion Date:	December 30, 1995
Funds:	$400,000

A more definitive understanding of capacity and level of service (LOS) at intersections with actuated controllers is needed to properly analyze their performance. The current version of Chapter 9 of the 1985 *Highway Capacity Manual* (HCM) has the following shortcomings regarding the treatment of these intersections:

1. Differences between the parameters needed to describe fixed-time and those needed to describe actuated intersections are not delineated in the current HCM procedure.
2. The current HCM procedure does not address important issues such as the types of detectors and their placement, vehicle extension, volume-density control, pedestrian actuations, isolated versus coordinated operations, arrival patterns, and phase shortening and skipping.
3. Predictions of LOS are not verified.
4. The HCM's methodology for estimating average cycle

lengths and green durations for actuated situations (Appendix II) may not be valid.

5. Convergence to fixed-time control performance at high and low volume is lacking.

6. The existing methodology does not support comparisons of the performance of actuated versus pretimed operations.

Improved methodology is needed to address these and other relevant issues. In addition, the methodology should be consistent with the requirements of the Intermodal Surface Transportation and Efficiency Act of 1991 and the Federal Clean Air Act Amendments of 1990, and be capable of accommodating traffic-responsive control envisioned in Intelligent Vehicle Highway Systems (IVHS).

The objective of this research is to develop a capacity and LOS analysis methodology for intersections with actuated control that can augment or replace the existing procedures in HCM Chapter 9. The procedure will be calibrated and validated through limited new field data, supplemented by existing field data and data from simulation/optimization programs.

The completed project will produce (1) a methodology capable of assessing the capacity and LOS for actuated intersections for typical design configurations; (2) a description of HCM Chapter 9 changes necessary to implement the methodology; and (3) draft material suitable for incorporation in the HCM that describes how the methodology is to be used, where it applies, and any limitations on its use.

In order to accomplish the research objective, the following tasks will be performed:

Task 1. Review current practices used by the traffic engineering community (e.g., state DOTs) for design and analysis of capacity at actuated intersections, and review the state of the art of analytical, empirical, and simulation/optimization-based analysis procedures.

Task 2. Develop a preliminary methodology that can assess the capacity and LOS performance of individual actuated intersections. Identify key design and operational parameters; recommend measures of effectiveness (MOEs) to be employed, including delay; explain the rationale for the methodology's use (e.g., its advantages relative to other options); and provide examples of its application using existing field data or simulation/optimization models, or both. The scope of this task is not intended to be all-inclusive, but rather is limited to the most typical signalized intersection designs using actuated controllers. For example, it could focus on intersections with multilane approaches, (including left-turn bays)—for both fully actuated (isolated) and semiactuated (coordinated) control types—and a spectrum of typical detectorization and controller schemes (e.g., a volume-density controller). Further, the methodology must be comparable with existing HCM Chapter 9 procedures for pretimed signals. Moreover, it must be developed at a level of detail suitable for operational analysis purposes and yet be amenable to planning applications.

Task 3. Assess the preliminary methodology developed in Task 2 by applying it to existing field data, augmented as necessary by data derived from simulation/optimization models. Revise the methodology as needed in response to the findings from this effort, and develop a plan for the pilot study (see Task 5) that will further calibrate and validate the methodology.

Task 4. Prepare an interim report presenting the results of Tasks 1 through 3. Specifically, it should focus on the findings from the current practice assessment conducted in Task 1, the rationale for the methodology developed in Task 2, the results of the methodology assessment conducted in Task 3, and the plan for the pilot studies of Task 5.

Task 5. Conduct pilot studies for a minimum of two conditions—fully actuated (isolated) and semiactuated (coordinated, e.g., as part of a network)—possibly at the same site. As part of this pilot study, assess the methodology's performance based on these new field data, and evaluate the adequacy of the data-collection plan.

Task 6. Revise and expand the pilot study plan to include additional sites and data-collection efforts for the analysis of a limited number of typical traffic-actuated intersection conditions. The plan must include the ability to measure and validate all key model assumptions, parameters, and performance measures. The plan should reflect the availability of previously collected data as well as the findings from the pilot studies conducted in Task 5.

Task 7. Collect data according to the plan developed in Task 4 and revised in Task 6. Data shall be collected under good weather conditions, at times not hampered by nonrecurring congestion, and under volume conditions that will allow assessment of a range of levels of service. Simulation/optimization models can be used to supplement the field data collected where gaps are identified.

Task 8. Reduce and analyze the data collected in Task 7, and further calibrate, validate, enhance, and document the methodology.

Task 9. Prepare a detailed final report describing the form, content, and rationale for the recommended capacity and LOS analysis procedures. The main report should document how the methodology should be applied, where it can be applied, and the accuracy of its MOE predictions. One appendix should indicate modifications to the existing HCM Chapter 9 that would be required to implement the methodology developed, and a second should provide the draft of a new Appendix II for HCM Chapter 9 that explains the methodology and its use.

Project 3-49 FY '94

Capacity and Operational Effects of Midblock Left-Turn Lanes

Research Agency:	University of Nebraska-Lincoln
Principal Invest.:	Dr. Patrick T. McCoy
Effective Date:	December 1, 1993
Completion Date:	February 28, 1996
Funds:	$300,000

Midblock left-turn lane treatments, which are important in meeting the access needs of motorists, directly affect accidents and roadway capacities. Although the safety records of multilane cross sections with flush or raised medians are generally well known, there are few, if any, studies that provide explicit information and data on the capacity and operational effects of these facilities. Research is needed to provide guidelines and criteria for selecting appropriate midblock left-turn lane treatments.

The objective of this project is to develop a quantitative methodology for evaluating alternative midblock left-turn lane treatments on urban and suburban arterials. The project results should be applicable to a full range of arterial cross sections, including raised medians and up to 7-lane flush cross sections. The product of this study should be in the form of a guide that allows the transportation practitioner to make decisions based on commonly available data.

The research should also produce a better understanding of the relationship between the type of midblock left-turn lane treatment and the adjacent traffic generators.

The project will be divided into two phases and will include the following tasks:

PHASE I. *Task 1.* Evaluate published and unpublished information on alternative midblock left-turn lane treatments and identify any ongoing research efforts that would have a bearing on the results of this project.

Task 2. Survey practitioners to determine current procedures, experiences, and needs with respect to evaluating alternative design treatments, and prepare a summary of current practice. As a minimum, the survey should address the following questions:

- How are design decisions being made today in the various agencies?
- What different types of midblock left-turn treatments are currently in use and what different types of transition treatments are employed?
- Has a breakpoint in traffic volumes been observed, above which two-way left-turn lanes are no longer effective? If so, does the breakpoint change according to the width of the cross section?
- Have practitioners previously conducted relevant studies?
- Are potential data-collection sites available?
- Have guidelines been developed for selecting midblock left-turn lane treatments?
- Which of the surveyed agencies would be willing to test the guide, developed in this research, prior to its publication?

Task 3. Based on Tasks 1 and 2, prepare a plan for developing an appropriate methodology for evaluating alternative midblock left-turn lane treatments. The plan should, as a minimum, address the following in a quantitative manner:

(a) Operational effects of midblock left-turn lane treatments on through traffic (including but not limited to travel time, midblock delay, and progression effects); (b) Operational effects of midblock left-turn lane treatments on mainline left-turning traffic (including but not limited to turn-lane queuing and occupancy, number of left-turn movements as a function of time and distance, distribution of the left-turns across driveways, and unsignalized intersections); (c) Capacity effects of midblock left-turn lane treatments on mainline through traffic, left-turn traffic, and minor street approaches (including but not limited to stopped delay, queuing, mainline access, and out-of-direction travel effects); and (d) Whether there are volume thresholds (or volume ranges) for any given multilane cross section, within which a particular midblock left-turn lane treatment is no longer effective. Such thresholds could be due to capacity, safety, or access considerations.

Although the emphasis of the research is on the elements previously discussed, consideration will also be given to the effects of the following on urban and suburban arterial operation, capacity, and safety: (a) vehicle mix; (b) spacing of crossovers for raised medians; (c) design treatments (including double-width lanes, a mixture of raised and flush median treatments, intersection alignment strategies for offsetting left turns, and transition treatments); and (d) abutting residential, commercial, and mixed land uses.

The data-collection plan should specify the number and types of sites to be investigated, identify the data items to be collected, and ensure that the data are collected in an appropriate variety of geographic and demographic settings.

If appropriate, a pilot study to test data-collection procedures and obtain a data sample may precede the full-scale data-collection effort.

Task 4. Submit an interim report that includes (a) a summary of current practice; (b) a synopsis of the literature and survey results, including potential sites for testing the guide; (c) recommended alternatives to be studied, data to be obtained, and measures-of-effectiveness to be used in evaluating alternatives; and (d) a detailed research plan and revised budget required to complete Phase II.

PHASE II. *Task 5.* Carry out the approved data-collection plan.

Task 6. Perform a comprehensive analysis of the data.

Task 7. Draft a guide for use by practitioners in evaluating alternative midblock left-turn lane treatments.

Task 8. Prepare a final report. The main body of the report shall document the study, and the guide shall be an appendix. In addition, the report shall contain a plan for implementation of the recommended guide.

Project 3-50 FY '94

Driver Information Overload

Research Agency:	COMSIS, Corporation
Principal Invest.:	Dr. Neil Lerner
Effective Date:	January 1, 1994
Completion Date:	March 30, 1996
Funds:	$300,000

Drivers are typically confronted with a multitude of traffic control devices displaying regulatory, warning, and guidance information. They must maintain the vehicle's position in traffic, monitor controls and instrumentation, observe the actions of other drivers, and sort through a collage of other information and visual distractions while trying to interpret the traffic control messages. For example, on an approach to a freeway interchange, current standards would permit more than 30 separate destination messages on 10 separate sign installations within less than 2 minutes driving time. The routing problem is further complicated by a multitude of destination-option messages when drivers exit to arterials from a freeway.

Research is specifically needed to define and quantify driver capabilities relative to information processing and to determine the influencing factors and thresholds for information overload. The results of this fundamental research then need to be translated into guidelines for the application of the full range of traffic control devices—including emerging Intelligent Vehicle Highway System (IVHS) technologies—to avoid information overload. Improved guidelines will enhance the safety and efficiency of highway networks.

The objective of this research is to develop guidelines for the design and application of traffic control devices to avoid driver information overload. To achieve this objective, it will be necessary to (a) identify and prioritize the driver information-processing requirements related to traffic control messages for freeways and arterials, (b) define and quantify the range of driver capabilities for information processing required for safe and effective performance of the driving task, and (c) identify factors that contribute to the driving workload and establish overload thresholds.

To accomplish this objective, the following tasks are anticipated: 1) Conduct a comprehensive review of the literature and ongoing research to identify applicable data on driver information detection, assimilation, and utilization; information overload; and the implications of these on traffic control device applications. This review should identify the factors influencing driver information processing and provide a summary and critique of driver information-processing models. 2) Contact transportation agencies to identify current practices to assess driver information-processing requirements and their influence on the design and placement of traffic control devices. Identify situations where particular driver groups are perceived to encounter information overload. Identify the range of traffic control devices used to provide warning, regulatory, and guidance information to the driver including highway advisory radio, in-vehicle displays, and traditional sign, signal, and marking treatments. 3) Outline a conceptual driver information-processing model appropriate for analyzing driver information overload considering the type of facility, design or operating speeds, roadway alignment, driver capabilities, and the features of the traffic control devices. 4) Prepare a study plan for gathering and analyzing information needed to refine and apply the driver information-processing model. Identify the types and amount of information necessary to refine and apply the model. 5) Prepare an interim report that documents the findings of Tasks 1 through 4, describes the efforts to be undertaken in Tasks 6 and 7, and discusses the expectations for the products of this research. 6) Execute the approved study plan, documenting the data gathered and providing interpretations of the results in the context of driver information overload. Revise the model, as appropriate, using the information gathered in this task. 7) Use the model to analyze the potentials for driver information overload for situations reflecting different roadway geometrics, ranges of traffic conditions, and varying driver groups. Estimate thresholds for driver information overload and translate these into draft guidelines for the design and placement of traffic control devices. 8) Submit the draft guidelines for an extended review by a group of knowledgeable professionals. The contractor will be expected to recommend modifications to the draft guidelines based on the reviewers' comments and to prepare a revised set of guidelines. 9) Document the efforts and findings of this research in a final report.

Project 3-51 FY '94

Communications Mediums for Signal, IVHS, and Freeway Surveillance Systems

Research Agency:	Kimley-Horn and Associates, Inc.
Principal Invest.:	Dr. Bruce C. Abernethy, P.E.
Effective Date:	November 15, 1993
Completion Date:	December 15, 1995
Funds:	$350,000

Historically, data transmission has been the weak link in traffic-management systems operating in both urban and rural areas of the United States. Most of these systems have employed either leased or user-owned hardwire as the communications medium.

As a result of continued development in urban areas, space on utility poles is virtually nonexistent and many duct systems are filled to capacity. Major reconstruction is frequently required for the addition of new cable needed for the continued expansion and enhancement of traffic-management systems. In many instances, decisions on new communication-system designs are constrained by the implementing agency's inadequate knowledge and experience with anything but conventional communications technology.

In rural areas, demographics and geographics have made the cost of needed transportation-related communications prohibitive. Transportation agencies appear reluctant to exploit advanced communications mediums from other fields (e.g., telecommunications, military, aerospace), primarily because of uncertainty about their potential for transportation application.

Nevertheless, advanced communication mediums offer viable alternatives to hardwire and could provide far more communication capacity. As we move into the era of Intelli-

gent Vehicle Highway Systems (IVHS), there is a critical need to expand our understanding of, and applications for, advanced communication mediums capable of reliable, high-capacity information exchange.

In early 1993, the Federal Highway Administration completed work on *FHWA Report No. FHWA-SA-93-052,* "Communications Handbook for Traffic Control Systems." This handbook, to be published and disseminated in the near future, was ". . . written to enable transportation engineers to plan, select, design, implement, operate and maintain communication systems for traffic control." NCHRP Project 3-51 is not intended to duplicate the FHWA study, but rather is intended to identify and fill gaps in the FHWA report and other related documents.

Research is needed to quantify, qualify, and synthesize the applicability of advanced communications technologies. Factors to be considered include initial capital costs, maintenance costs, availablity of standards, applicability of particular mediums to both existing and future traffic management strategies, and any limitations specific to geographical areas.

The objectives of this project are to assess advanced communication mediums applicable to traffic-signal, IVHS, and freeway-management systems and to provide guidance to transportation-related agencies on selection, design, deployment, maintenance, and staffing for using such mediums in transportation-management communication systems.

To achieve the objectives, the following tasks will be performed:

PHASE I. *Task 1.* Conduct an in-depth search for existing documentation, including but not limited to, reports, manuals, standards, and specifications for both conventional and advanced communication mediums having potential application to traffic-signal, IVHS, and freeway-management systems.

Task 2. Select a sample of users and conduct a survey to determine: 1) strengths and limitations of publicly available information on both conventional and advanced communication media; 2) planned system requirements that influence communication-medium selection for both new and retrofit applications; 3) current policies and strategies for implementing communication mediums; 4) technical constraints and impediments to implementation that have been experienced; 5) perceived obstacles such as lack of standardization or unfamiliarity by potential users with technology applications; and 6) institutional impediments.

Task 3. Prepare and submit within 5 months an interim report on Tasks 1 and 2 including 1) an annotated bibliography; 2) a survey summary with a matrix of informational needs versus resources available; 3) based on the results of Tasks 1 and 2, a list of the conventional and advanced communication mediums selected for further study; and 4) recommended changes to the work plan for the remaining tasks.

PHASE II. *Task 4.* Building on currently available documentation, evaluate cost and reliability data for conventional communication mediums to serve as a baseline reference for a comparative analysis of advanced communication mediums. Reliability figures and costing should be developed to show, as a minimum, trends in equipment availability, installation and maintenance costs, and levels of reliability for all mediums.

Task 5. Prepare a table of characteristics for all communication mediums selected in Task 3, including but not limited to, achievable transmission rates, requirements for and frequency of the need for signal restoration, the need for line conditioning, any amplification requirements, potential hazards and other specialized physical or electrical features needed for the use of such mediums in system applications, and potential impediments to future integration of the various communication mediums.

Task 6. For each advanced medium having future implementation potential, identify the requirements and provide costs for any specialized equipment needed for installation and maintenance. Define the skill levels required for installation and maintenance staffing.

Task 7. Develop and tabulate initial installation costs for each advanced communication medium including both materials and labor. Using current records or estimates, develop expected annual maintenance costs. Costing should be estimated separately for rural, suburban, urban, and metropolitan areas. Estimate the expected service life of each medium.

Task 8. Based on the technological constraints and institutional impediments identified in the Task 2 survey, develop strategies and tools to facilitate the acceptance of advanced communication mediums that will address policy and decision-making concerns.

Task 9. Prepare a final report with an executive summary of all findings and conclusions. The report should include a complete comparative analysis of all mediums with supporting information for all conclusions and recommendations. In addition, the report shall contain a plan for implementation of the research results.

AREA 4: GENERAL MATERIALS

Project 4-15 FY '82

Corrosion Protection of Prestressing Systems in Concrete Bridges

Research Agency:	Wiss, Janney, Elstner Associates, Inc.
Principal Invest.:	William F. Perenchio
Effective Date:	July 1, 1982
Completion Date:	November 30, 1985
Funds:	$249,973

The use of deicing salts or the existence of a marine environment presents a potential problem of chloride-induced corrosion of prestressing steel embedded in concrete bridge members—a problem that could ultimately lead to major structural damage. This potential problem is of particular concern in segmental bridges where the prestressing

steel is located in close proximity to the deck or other exposed surface.

Good quality construction minimizes the potential corrosion of prestressing steel. Unfortunately, this is not always the case under actual field conditions and construction practices. Low permeable membranes and overlays, concrete sealers, and various methods of decreasing permeability of concrete are being used, but confidence in the long-term protection of prestressing steel is lacking. Therefore, more positive steps were needed to instill confidence in the use of prestressing steel in a chloride-potential environment.

Accordingly, techniques and materials to provide enhanced corrosion protection for prestressing steel and its associated metallic hardware in pretensioned and post-tensioned concrete bridges were reviewed. In addition, a year-long, accelerated corrosion test program on epoxy-coated strand, polyethylene duct, epoxy-coated steel duct, epoxy-coated anchorage hardware, grouts modified with silica fume and with calcium nitrate, and heat-shrink tubing for sealing post-tensioning duct joints, together with traditional materials was undertaken on pretensioned and post-tensioned members.

The research project is complete, and the principal findings have been published in NCHRP Report 313, "Corrosion Protection of Prestressing Systems in Concrete Bridges." Further detail is available in an agency report entitled *Supplement to NCHRP Report 313,* "Corrosion Protection of Prestressing Systems in Concrete Bridges, Appendices A,B,-C,D,E,F." These appendices provide additional information on the literature search and the conduct of the various experiments. The supplemental report was distributed to NCHRP sponsors only. However, others may obtain loan copies or purchase ones for the cost of reproduction (see final page of this document for ordering information).

Project 4-16 FY '84

Cost and Service Life of Pavement Markings

Research Agency:	Pennsylvania State University
Principal Invest.:	Dr. John J. Henry
Effective Date:	October 1, 1984
Completion Date:	September 30, 1988
Funds:	$340,327

A wide variety of materials is available for the marking of streets and highways. Traffic paints have been the mainstay of marking materials for the past 60 years, but the recognition that such paints have severely limited serviceability in locations of high traffic volumes and/or extreme climate has led in the past 20 years to the increasing use of "durable" marking materials.

Traffic paints are either latex-based or solvent-based comprised of alkyd, chlorinated rubber, or epoxy resins. In severe service conditions such materials may provide 6 months or less useful life. Durable marking materials generally are solventless systems and can be epoxy, polyester, or either hydrocarbon or alkyd thermoplastic materials. Their service life when properly applied can approach 3 or more years. Traffic paints traditionally have been applied by state and municipal forces, whereas durable marking materials are generally applied by private firms under contract.

At present, applied traffic paints can cost from $0.025 to $0.06 per lineal foot (4-inch line), while durable markings can cost from $0.055 to $1.25 per lineal foot. Cost disparities also exist for special markings, such as crosswalks, turn arrows, and other in-lane markings. A higher initial cost may be justified if the effective service life of the durable material exceeds that of traffic paint in the same location. Higher costs may also be justified by the more intangible benefits of continuous, year-round delineation and reduced exposure of striping personnel and the public to hazardous striping operations. Such benefits are particularly important for special markings. In some cases, environmental restrictions may dictate the selection of marking materials.

The judgment of whether the cost of a material is reasonable for a particular set of circumstances (climate, traffic volume, condition of previous markings, pavement type, highway geometry, etc.) should be made on the basis of its probable service life. However, factual data on which to base such judgments are scarce. Some general information is available from field tests and operational use of various types of pavement marking materials, but there has been little to no specific treatment of the problem of how to select a cost-effective marking material for a particular set of circumstances. In addition, the influence of width (4, 6, and 8 inches) on the effective service life of traffic lines has not been established. This lack of comprehensive data is disturbing in light of stringent budgets.

The objective of this research was to determine the typical "on-road" service life and cost of various types of pavement marking materials and to quantify how major external factors affect service life. Maximum use was made of existing information from field tests and operational installations, and a limited amount of new field testing was conducted. Guidelines were developed for the use of commercially available pavement marking materials, including selection criteria affecting the optimum balance between cost and service life. The materials evaluated included: paint, epoxy, epoxy paint, alkyd and hydrocarbon thermoplastics, polyester paints, epoxy thermoplastic, and preformed materials. The research tasks included:

1. Compile comparative data on the performance and total cost installed of commercially available traffic paint and durable marking materials through a critical review of published results, a survey of selected state and large municipal highway agencies, and personal follow-up where appropriate.

2. Critically analyze the data to develop comparative estimates of the service life of traffic paint and durable marking materials within the ranges of external factors, such as climate, traffic volume, traffic mix, highway geometry, and

type and condition of pavement and previous markings. Develop estimated installed costs per foot for each material type.

3. Prepare an interim report with a detailed test plan for Task 4. Prepare a priority listing of *all* tests needed to provide information covering the full range of materials and conditions. From this list, select specific materials and conditions for field testing within the limited funds of this project.

4. Conduct tests according to the approved test plan.

5. Prepare guidelines for selection of the appropriate pavement marking materials identifying the effects of major external factors. The intent of these guidelines is to allow users to determine life-cycle costs for various marking materials.

The research was completed, but since many of the marking materials did not fail at the test decks during the observation periods, the relationships between costs and service life could not be fully ascertained.

The full research report is available on a loan basis and the findings are summarized in Research Results Digest 178.

Project 4-18 FY '92

Design and Evaluation of Large Stone Mixtures

Research Agency: Texas A&M Research Foundation
Principal Invest.: Joe Button
Effective Date: June 1, 1992
Completion Date: November 30, 1994
Funds: $300,000

Rutting of asphalt pavements subjected to high traffic volume, heavy wheel loads, and high tire contact pressures is a major concern. Several approaches to mitigating this problem are being used; one that shows potential is the use of large stone mixtures (LSM). The introduction of larger sizes and higher proportions of the coarse aggregate fraction is intended to change the basic structure of the mixture such that the loads are supported by direct stone-on-stone contact. LSM performance may be less dependent on binder type and content than conventional mixtures. Higher void content, however, could lead to stripping problems. Field experience has indicated that there are concerns associated with constructibility, such as incomplete coating of aggregates, segregation, aggregate breakage, and inadequate compaction.

Potential benefits have led several states to construct a number of LSM pavements. However, a variety of mixture design methods, aggregate gradings (e.g., well-graded, stone-filled, or open-graded), and construction procedures were used with mixed results. Because of the growing interest in this concept, there is an urgent need for laboratory and field evaluation of performance characteristics to determine the effectiveness of LSM in minimizing plastic deformation. Additionally, a definitive design procedure needs to be developed for LSM.

The objectives of this study are (1) to evaluate the effectiveness of LSM in resisting plastic deformation in asphalt pavements, (2) to recommend a design procedure for the proportioning of aggregate and binder, and (3) to provide guidance on constructibility. The research effort shall consider the effects of aggregate shape, grading, and binder characteristics on LSM performance. The scope of this research shall include LSM having a maximum aggregate size between 1 in. and 2 ½ in., inclusive.

Accomplishment of these objectives will include the following tasks: (1) Review and analyze currently used laboratory design procedures, specifications, and construction practices for LSM. (2) Collect and analyze LSM field-performance data, including traffic information and environmental conditions, to assess the effectiveness of LSM in minimizing plastic deformation. (3) Submit an interim report within 9 months after initiation of the research. (4) Develop a mixture-design procedure to determine the optimum proportions of the aggregate and binder to be used in LSM, including specimen fabrication, test methods, and mixture design criteria. (5) Develop detailed laboratory test procedures to evaluate the resistance of large stone mixtures to plastic deformation and moisture damage. (6) Based on available information, develop guidelines for equipment requirements and construction practices for handling and processing mixture components in the plant and for laydown of mixtures in the field to minimize segregation and aggregate breakage and ensure adequate compaction. (7) Prepare a final report documenting the research effort and the research findings.

Research is underway. Tasks 1–3 have been completed. The interim report has been approved by the committee and the consultant has begun work on the remainder of the project.

Project 4-19 FY '94

Aggregate Tests Related to Asphalt Concrete Performance in Pavements

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (36 Months)
Completion Date:
Funds: $500,000

The properties of coarse and fine aggregates used in hot-mix asphalt concrete mixtures are very important to the performance of the pavement system in which they are used. Often pavement distress, such as stripping and rutting, can be traced directly to improper aggregate selection and use. Clearly, proper aggregate selection is necessary for attaining desired performance.

Many of the current aggregate tests were developed to empirically characterize an aggregate without, necessarily, any relationship to the performance of the final product incorporating that aggregate. Although widespread use, fa-

miliarity, and a historical database have perpetuated the popularity of some tests, the highway industry would be better served by other tests that would provide a clearer relationship to performance.

Thus, research is needed to evaluate existing aggregate tests, identify new tests that relate to performance, and develop better procedures for testing and selection of aggregate used in various hot- mix asphalt concrete applications. These applications include the different layers of asphalt and portland cement concrete pavements and overlays.

The objective of the research is to recommend a set of aggregate tests that relate to the performance of hot-mix asphalt concrete used in pavement construction. This research will include the evaluation of existing aggregate tests to assess their ability to predict pavement performance and, where this predictive ability or clear relationship to performance is lacking, the development of new tests.

To accomplish this objective, the following two research phases will be conducted:

Phase I: (1) Identify the performance parameters of hot-mix asphalt concrete used in pavement construction that may be affected by the properties of the aggregates. (2) Identify the aggregate properties that influence the performance parameters identified in Task 1, and can be used to predict the pavement performance. Physical, chemical, mechanical, and petrographic characteristics shall be considered. The research shall consider all aggregate types and size fractions, including material passing the No. 200 sieve and changes in aggregate characteristics due to degradation during handling. (3) Identify and evaluate with consideration to performance predictability, precision, accuracy, practicality, cost, and other pertinent factors those test procedures currently used in the U.S.and other countries for measuring properties of aggregates used in hot-mix asphalt concrete. Determine which tests can be used to measure the properties identified in Task 2. (4) Identify potential techniques for measuring those performance-related properties for which no suitable test method has been identified in Task 3. Evaluate and rank these techniques considering the same factors used for evaluating available test procedures. (5) Develop a research plan that encompasses a laboratory investigation to evaluate and validate the techniques and test methods identified in previous tasks, for measuring aggregate properties that relate to pavement performance. The research plan, to be executed in Task 7, should describe rationale, methods, laboratory tests, validation and calibration requirements. It should also address repeatability and reproducibility of the tests proposed in this investigation together with other required details. (6) Prepare an interim report that (a) documents the research performed in Tasks 1 through 5 and (b) provides a work plan for the Phase II portion of the project, outlining schedule, budget, and other details. Following review of the interim report by the project panel, the research team will be required to make a presentation to the project panel.

Phase II: (7) Execute the research plan, including the laboratory test program, approved in Task 6. Based on results of this work, recommend a set of tests for evaluating aggregates used in different hot-mix asphalt concrete applications. (8) Develop protocols for the tests recommended tests in Task 7, in a format suitable for consideration and adoption by AASHTO. (9) Submit a final report that documents the entire research effort. The report shall include a plan for validating the relationship of the proposed tests to pavement performance in the long term, and an implementation plan for moving the results of this research into practice.

AREA 5: ILLUMINATION AND VISIBILITY

Project 5-10 FY '88 and FY '89

A Mobile System for Measuring Retroreflectance of Traffic Signs

Research Agency: EKTRON Applied Imaging
Principal Invest.: John Lumia
Effective Date: September 7, 1987
Completion Date: December 31, 1990
Funds: $480,795

Traffic signs are very important components of streets and highways. Ideally, they help motorists find their way in a safe manner by providing for the orderly and predictable movement of traffic. In order for signs to accomplish their intended purposes, they must be visible to the motorists at all times. While sign visibility is generally not a problem during daylight, at night signs with inadequate retroreflectance may not be sufficiently visible and can contribute to accidents.

Most signs are made from retroreflective materials that tend to deteriorate over time leading to ineffective performance at night. Consequently, there is a serious need to establish requirements for sign visibility and to devise a practical system for evaluating the condition of existing signs and providing data for decisions on sign replacement or refurbishment. At the present time, there are laboratory methods and portable instruments available for measuring retroreflectance, but easy-to-use mobile systems are not available. Practical, safe, and cost-effective methods to measure the retroreflective characteristics of in-situ signs from a mobile highway unit need to be investigated. The research requested in this proposal will determine the feasibility of developing such a system.

The objectives of this project are (1) to develop a system concept for the rapid assessment of retroreflective effectiveness of signs, and (2) to demonstrate the feasibility of the system concept by devising and testing a proof-of-concept model.

The system is to be useful in determining the need for sign replacement or refurbishing. The system is to be capable

of measuring the retroreflectance of sign legends and backgrounds irrespective of color, size, and placement. For safety and economic reasons, it is preferable that the system be operational during daylight from a moving vehicle.

To accomplish the objectives, the following tasks have been conducted:

Task 1—Review the literature dealing with retroreflective signs used on streets and highways.

Task 2—Develop a concept for a system of equipment and procedures for the rapid assessment of retroreflective effectiveness of signs. The system concept should accommodate the impact of changes in daylight, speed, and geometrics during in-motion measurements.

The system shall be designed to:

- Produce sign retroreflectance readings at a low unit cost (capital and operating), per sign.
- Evaluate signs of various sizes, colors, and positioning.
- Operate in a manner that does not pose a danger to the operator or the passing motorist.
- Be sufficiently reliable to allow highway agencies to comply with existing and/or pending reflectance regulation.
- Produce retroreflectance output in units of candelas per foot-candle per square foot.
- Be capable of being operated by highway maintenance technicians during daylight with a minimum amount of calibration needed.

Task 3—Select a suitable system components and design a system, including required computer software for data collection and reduction. Build a breadboard model for proof-of-concept testing.

Task 4—Conduct laboratory tests to evaluate the system's performance and capabilities, modifying the system design and model as necessary. Perform measurements on representative signs under day and night conditions at varying distances and orientations. Compare these measurements with those obtained using conventional methods (Federal Test Method Standard 370, ASTM E-810, FP-85).

Task 5—Develop an implementation plan for producing an operational prototype system capable of measuring retroreflectance of in-situ signs from a moving vehicle during daylight. This plan shall include:

- Statement of work including the tasks to be performed.
- Proposed budget.
- A list of required system performance specifications.
- Estimate of the final (production) system capital and operating cost.

Task 6—Prepare a Final Report

Work on Tasks 1 through 6 was successfully completed and has been categorized as Phase I in the overall development of the mobile system. In Phase I, a laboratory model of the measurement system was developed and the proof-of-concept testing was successfully completed. Recommendations were made for a mobile prototype to be developed under a Phase II effort. The project panel met to review the Phase I results and consider the proposed Phase II effort. The panel agreed that the feasibility of a mobile system had been demonstrated and approved the Phase II effort.

Loan copies of the Phase I final report are available from the NCHRP.

The work conducted under Phase II was as follows:

Task 1. Produce a conceptual design for a prototype Mobile System for Measuring the Retroflectance of Traffic Signs (MSMRTS) based on the Phase I breadboard system and results. Select/recommend a vehicle suitable for installation and testing of the MSMRTS, based on the mechanical and electrical design requirements of the prototype. Investigate measurement accuracy due to lowering the maximum retroreflectance capability of the system, and develop a mathematical model to predict overall measurement error based on individual component errors. Prepare a presentation of the conceptual design for review and approval.

Task 2. Develop a plan for testing the mobile prototype. This plan will define the signing material, age, and category of sign samples to be tested. System operating modes and vehicle speeds shall also be considered.

Task 3. Build the prototype MSMRTS including: detailed design, fabrication, assembly, subsystem integration, and testing.

Task 4. Acquire a van-type vehicle including auxiliary generator and prepare vehicle for installation of the prototype MSMRTS.

Task 5. Install the MSMRTS on the vehicle and test the prototype system. Perform mobile and stationary measurements of street and highway signs. Evaluate the measurement accuracy of the mobile system while under way.

Task 6. Develop final system specifications. Present revised estimate of final system capital and operating costs.

Task 7. Prepare a final report and demonstrate the MSMRTS prototype.

All work has been completed. The prototype MSMRTS was successfully demonstrated to the project panel in Bedford, Mass., on June 15, 1990. Final delivery of the van with all hardware and software was made on November 15, 1990. The final reports will not be published in the regular NCHRP report series. Loan copies of the Phase I and Phase II reports are available from the NCHRP.

Project 5-11 FY '89

Implementation Strategies for Sign Retroreflectivity Standards

Research Agency:	Bellomo-McGee, Inc.
Principal Invest.:	Dr. Hugh W. McGee
Effective Date:	February 15, 1989
Completion Date:	August 31, 1991
Funds:	$203,544

Traffic signs are very important components of streets and highways. Ideally, they help motorists find their way in a safe manner by providing for the orderly and predictable movement of traffic. For signs to accomplish their intended purposes, they must be visible to the motorists. Although sign visibility is generally not a problem during daylight, signs with inadequate retroreflectivity may not be sufficiently visible at night and can contribute to accidents. In the context of this research, retroreflectivity is intended to encompass the characteristics of legibility, visibility, and conspicuity.

On April 26, 1985, the Federal Highway Administration published an Advance Notice of Proposed Amendment to the *Manual on Uniform Traffic Control Devices* as the initial step in developing performance standards for in-service, retroreflective, traffic-control devices. Since then, research has been initiated to determine minimum visibility requirements for traffic signs that will satisfy the needs of the nighttime driving population. In addition, research is underway to develop field measurement tools to determine whether a specific in-service traffic sign meets given retroreflectivity levels.

However, before retroreflectivity standards can be implemented, their potential economic impact must be assessed. Further, any adverse effects of such standards should be mitigated. The results of this project will provide alternative strategies for economical ways to improve the effectiveness of signs within available resources.

The objective of this project is to determine the economic consequences of alternative standards for retroreflective traffic signs. Accomplishment of the objective will involve collection of retroreflectivity data on representative traffic signs in diverse geographic regions. Study areas will include both urban and rural roadways and will be large enough to adequately represent a range of maintenance conditions and classes of roadways. This study shall not include construction and maintenance signs.

To accomplish the objectives, the following tasks are being conducted:

Task 1. Evaluate the literature and other informational sources pertaining to retroreflectivity of traffic signs. The various types of sign inventory systems in use and current maintenance practices shall be investigated.

Task 2. Review the references noted below and summarize information pertinent to establishing the feasibility of retroreflectivity standards.

Task 3. Use, where appropriate, the latest results and findings from the following research projects:

(a) NCHRP Project 5-10, "A Mobile System for Measuring Retroreflectance of Traffic Signs."

(b) FHWA Contract No. DTFH61-87-R-00008, "Minimum Visibility Requirements for Traffic Control Devices."

(c) FHWA Contract No. DTFH61-88-R-00060, "Service Life of Retroreflective Traffic Signs."

Task 4. Develop a data collection plan to include, as a minimum, the following:

(a) Identify the study areas and the sign and roadway categories to be sampled.

(b) Select the locations for sampling. These should be diverse not only by region, but also by governmental level (e.g., federal, state, city, county) and maintenance policy. The sample size should be sufficient to allow statistically valid estimates of the retroreflective conditions and the distribution of signs by class of roadways.

(c) Prepare a detailed data collection plan.

Task 5. Submit an interim report to include the results of Tasks 1 to 4 and meet with NCHRP Project Panel for approval of the data collection plan.

Task 6. Collect existing data on in-service sign retroreflectivity, replacement costs (e.g., labor and material), and other information utilized by sign management programs.

Task 7. Analyze the data:

(a) For different categories of signs, develop relationships that indicate how various retroreflectivity standards would affect, nationally and at state and local levels: (i) the number of signs to be replaced, (ii) the replacement costs, and (iii) any other economic or management considerations.

(b) Describe the modeling techniques used and segregate data so they can be applied readily to any jurisdiction's sign replacement and maintenance programs.

Task 8. Develop economic-based implementation strategies for alternative sign-retroreflectivity standards across different categories of signs, roadways, and jurisdictions.

Task 9. Recommend several options for system-wide implementation that:

(a) Provide guidelines for phasing in the implementation of retroreflectivity standards.

(b) Indicate the expected economic consequences of adoption of these standards.

Task 10. Prepare the final report.

All work has been completed and the final report has been published as *NCHRP Report 346,* "Implementation Strategies for Sign Retroflectivity Standards." (See last page of this document for ordering information.)

Project 5-12 FY '92

Requirements for Application of Light Emitting Diodes (LEDs) to Traffic Control Signals

Research Agency:	Lighting Sciences, Inc.
Principal Invest.:	Dr. Ian Glen Lewin
Effective Date:	February 15, 1992
Completion Date:	August 15, 1994
Funds:	$249,973

Currently, incandescent lamps are the predominant source for traffic signal lighting. Yet, incandescent lamps are inher-

ently inefficient in converting electrical energy into light when compared to other light sources. The useful life of an incandescent lamp is also much shorter than other sources. As a result, maintenance costs are high, and the lamps must be changed many times during the life of the signal head. Furthermore, the effective light output of an incandescent lamp decreases over its life.

All of these disadvantages of the incandescent lamp, when coupled with the increasing cost of electrical energy, make it important and timely to consider a more economical light source such as light emitting diodes (LEDs). Although there are other light source technologies that could replace incandescent lamps, this project is limited to applications of LEDs to all types of traffic control signal indications. The research shall include evaluation of the performance characteristics, human factors aspects, and economic impact of LED technology for traffic control signals.

The objectives of the project are: (1) to determine the feasibility and implementation potential of LEDs for traffic control signal indications, i.e., vehicle, pedestrian, and lane-use; (2) to demonstrate and evaluate the technology in both laboratory and field applications; and (3) to provide recommendations for needed changes to current traffic control signal standards.

Accomplishment of these objectives will require at least the following tasks: (1) Review the literature and standards dealing with traffic control signals in the areas of performance characteristics, human factors, and economics. Assess the potential applicability of LED technology to traffic control signals. (2) Review the existing performance requirements of traffic control signals and evaluate the performance characteristics of LEDs against the requirements. Performance characteristics of LEDs to be evaluated should include, but not be limited to: colorimetry, photometry, useful service life, and environmental problems such as sun phantom, electrical surges, temperature, and ultraviolet exposure. Develop and document appropriate methodology for evaluation of critical performance characteristics. Fabricate the following prototype traffic signal faces for subsequent laboratory and potential field evaluation: (a) 8-in. red, yellow, and green circular vehicular signal face; (b) 12-in. red, yellow, and green circular and arrow vehicular signal face; (c) 12-in. symbolic pedestrian; and (d) 12-in. lane use. Prototypes should be electrically and mechanically compatible with existing signal equipment. Note: The research should address the issue of obtaining orange and white pedestrian signal indications using LEDs. (3) Determine human-factors and safety performance of LEDs in terms of visibility, conspicuity, visual field, degree of visual uniformity, user expectations, and driver characteristics such as age, color vision, and other visual anomalies. This task shall include laboratory assessment of human performance with prototypes developed in Task 2. (4) Assess economic implications including initial and life cycle costs, energy efficiency, retrofit capability, reliability, maintainability, and useful service life including a definition for "end of life." (5) Evaluate the data from Tasks 1 to 4 and recommend the geometric, traffic, and environmental conditions for which each Task 2 prototype design is most suitable. Prepare and submit an interim report describing the results of Tasks 1 to 4 including a detailed plan for field testing and evaluation to be undertaken in Task 6. The interim report shall be submitted within 12 months after the contract is awarded. Research on the remaining tasks shall not be initiated until the interim report has been approved by the NCHRP. (6) Conduct field tests under realistic conditions to evaluate the safety and effectiveness of LED traffic signal indications in terms of Task 3. Collect operational and cost data on the prototypes during the field tests. (7) Based on the results of Task 6, revise the human factors assessment developed in Task 3 and the economic implications developed in Task 4. (8) Compare the performance characteristic of LED traffic signal indications with existing ITE, CIE, and MUTCD standards and develop recommendations for changes in these standards as needed. (9) Provide guidelines for the use of LED traffic control signal indications based on the results of Tasks 1 to 8. (10) Prepare a Final Report documenting the results of Tasks 1 to 9, including fabrication drawings and pertinent information from the interim report.

Tasks 1 through 5 have been completed and the project panel is reviewing the interim report.

Project 5-13 FY '93

Illumination Guidelines for Nighttime Highway Work

Research Agency:	The University of Florida Research Foundation, Inc.
Principal Invest.:	Dr. Ralph Ellis, Jr. and Zohar Herbsman
Effective Date:	February 1, 1993
Completion Date:	October 31, 1994
Funds:	$173,979

An increasing amount of highway work, on both divided and undivided highways in urban and rural settings, is being performed during nighttime hours to minimize the congestion effects of daytime reductions in capacity and to accelerate the work. This often necessitates the use of illumination to facilitate the work while maintaining a safe work area for the traveling public and the workers. Guidelines for illumination systems need to be developed and made available to public agencies and contractors. At this time, there are no guidelines that specifically address nighttime illumination for highway maintenance and construction. Without guidelines, illumination will continue to be provided on a trial and error basis, which can be costly in both time and safety.

Some states have studied the effectiveness and safety of nighttime construction and maintenance work, but these studies have not adequately addressed illumination needs for different types of work activity. Proper light intensities and sources, height and pattern of illumination devices,

shielding light sources from the traveling public, and temporary lighting for roadways passing through the work zones need to be considered. Other factors that may warrant study include (1) the effect of illumination on safety devices used in the work zone such as signing, pavement markings, reflectors, equipment markings, and channelization devices; (2) the effects of transitions to and from illuminated areas by both motorists and workers; and (3) the visibility of the worker to the motorist and the worker's ability to see moving vehicles.

The objective of this research is to develop guidelines that can be used by public agencies and contractors in determining the types of light sources and the minimum and maximum levels of illumination for a variety of nighttime work in typical highway situations. The guidelines should also indicate when lighting on adjacent roadways is necessary, and what the lighting levels should be to meet the visibility requirements of the motorists passing through the work zone.

It is envisioned that this research will include at least the following tasks: (1) Review recent and ongoing research projects, as well as pertinent domestic and foreign documents, to determine illumination needs, established requirements, and safety and performance implications for both the traveling public and the highway workers. Contact knowledgeable individuals from public agencies, construction firms, utility companies, and manufacturers to determine current practices for establishing illumination levels for various types of nighttime work. Summarize the range of nighttime construction and maintenance work that is done and compare the illumination criteria used by different agencies. Identify the illumination devices that are available and categorize them by pertinent features. (2) Conduct field reviews of typical nighttime work sites to collect data about current practices, decisions made in the field, worker perspectives, and motorist reactions. Proposers should describe the process that will be used for these reviews and indicate the number and type of study sites that they anticipate visiting. The findings of Tasks 1 and 2 should be documented in a working paper. (3) Based on worker needs, define illumination requirements for the activities associated with typical nighttime construction and maintenance work. Where no illumination requirements exist for highway work activities, derive them from relevant standards for similar nonhighway work activities. Where differing standards exist, assess the implications of the different illumination requirements and recommend appropriate levels. Evaluate the feasibility of the derived illumination requirements relative to construction and maintenance practices and lighting equipment capabilities. Determine the need, if any, for experiments to establish nighttime lighting levels. (4) Assess the impacts of nighttime work illumination requirements on motorist visibility including the effectiveness of various practices for the intensity, placement, and shielding of work area lighting to minimize adverse effects on motorists traveling through the work zone. Evaluate the need for additional temporary roadway lighting to permit safe and effective nighttime work. These assessments should consider the range of conditions that would normally be encountered during night work in urban and rural areas. (5) Determine if additional data are needed to validate or establish illumination requirements or to assess impacts on motorists. Design experiments to verify available information and collect new data, if needed. Prepare an experimental plan that will describe the testing strategy, methods to be used, situations and samples, and outline processes for the organization, manipulation, and interpretation of the data gathered. Conduct pilot studies as necessary to test the feasibility of elements of the plan. The plan should be devised to gather as much pertinent information as possible from the experiments. (6) Prepare an interim report that (1) summarizes the findings of Tasks 1 through 5 and (2) outlines how guidelines for the lighting designer will be developed. The interim report should provide a table of contents and format for the proposed guidelines document. The contractor will participate in an interim meeting with the panel to develop a consensus on the planned efforts and the form and content of the guidelines. (7) Conduct experiments as designed in Task 5 and approved by the panel in Task 6 to understand the factors affecting worker performance and the impacts on motorists in the vicinity of illuminated work zones. Determine visibility, conspicuity, and other measures appropriate for evaluating the performance of all categories of drivers. Analyze the results to determine illumination requirements to be incorporated into the guidelines. (8) Develop guidelines for the lighting designer through a synthesis of current practices and the results of the experiments. The guidelines should indicate illumination levels and configurations that maximize human performance and safety. The contractor should recommend a format that incorporates the best presentation features of other lighting guidelines. Analyze the trade-offs among safety, cost, traffic flow, and work productivity relative to different illumination factors. The guidelines should cover typical highway situations. (9) Prepare a final report that documents the entire research effort in accordance with NCHRP requirements. The report shall include the recommended guidelines in the format of a stand alone document. The contractor will be expected to revise the guidelines and the draft final report based on the project panel's review.

Research on Tasks 1 through 5 has been completed, and the interim report is being reviewed by the project panel.

Project 5-14 FY '93

Advance Warning Arrow Panel Visibility

Research Agency:	The Last Resource, Inc.
Principal Invest.:	Mr. Doug Mace
Effective Date:	January 2, 1993
Completion Date:	February 28, 1995
Funds:	$275,000

Advance warning arrow panels are generally accepted as one of the most effective devices available where temporary activities or events necessitate changes in traffic patterns. These devices are used to guide traffic in construction and maintenance areas and to provide supplemental information to motorists for incident management purposes. Timely detection and recognition of arrow panels is essential to assure proper motorist action. Commercially available arrow panels provide varied levels of visibility because there are no performance standards. This variation is most evident in the solar-powered arrow panels, which offer operational advantages but may not provide visibility levels comparable to generator or line-powered units. To ensure that arrow panels provide adequate visibility, performance requirements based on the critical visibility factors are needed. In addition, practical procedures that can quickly and easily evaluate in-service performance of arrow panels are needed.

The objectives of this research project are: (1) to identify and evaluate the factors affecting the detection and recognition of arrow panels, (2) to develop performance requirements for arrow panels operating under various conditions, and (3) to develop practical, reliable means for checking arrow panel visibility, as perceived by the motorist.

It is envisioned that this research will include at least the following tasks: (1) Review existing literature and current practices to identify factors that are likely to affect arrow panel visibility. Relevant factors include light source, intensity, beam pattern, color, electrical power consumption, panel size, panel and light source orientation, ambient lighting levels, dimming capabilities, sun shading, and power characteristics. Identify current practices for utilization, placement, maintenance, and in-service evaluation of arrow panels by contacting public agencies, utility companies, construction and maintenance contractors, and other users. (2) Prepare an experimental plan, which will describe laboratory experiments, closed and open field tests, analytical studies, computer simulations, or other procedures necessary to examine the factors affecting the visibility of arrow panels. The plan should describe in detail the tests to be conducted, the rationale used to isolate important factors, the measures of performance to be used, sample descriptions and sizes, the sequence of experiments, and the processes for the analysis and interpretation of the data gathered. (3) After NCHRP approval of the experimental plan, conduct the evaluation of the factors in accordance with the plan. The evaluation should cover a practical range of field situations, driver characteristics, day, night and transitional ambient lighting conditions, and other environmental situations. (4) Based on the findings of Tasks 1 through 3, develop technical requirements necessary to ensure adequate arrow panel visibility. Compile the recommended requirements in a format that can readily be adapted for use by (a) transportation agencies as purchasing and operating specifications for arrow panels and (b) hardware manufacturers as a means to ensure that products meet the accepted performance levels. The contractor shall prepare an interim report that (a) documents the experiments and results, (b) interprets the findings, and (c) recommends performance requirements for arrow panels. The contractor will meet with the project panel to discuss the report. (5) Develop simple, straightforward procedures for use by maintenance and field personnel to assess the adequacy of in-service arrow panel visibility and to initiate simple corrective actions to improve visibility, if necessary. Because arrow boards must provide reliable, consistent operation under a variety of field conditions, including highly variable ambient light levels and different roadway geometry, the procedures must be sensitive to these conditions. (6) Assess the functionality of the procedures by having them performed by maintenance and field staff from at least five potential user organizations. Report the findings of this assessment along with any recommendations for changes to the procedures. Revise the procedures where there is consensus of the panel. (7) Prepare a final report that includes the requirements and procedures developed as appendices.

The research is continuing after the panel approved the experimental plan at the interim meeting.

AREA 6: SNOW AND ICE CONTROL

Project 6-12 FY '91

Improved Visibility for Snow Plowing Operations

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	(36 months)
Completion Date:	
Funds:	$300,000

Snow and ice control may be the most hazardous duty faced by highway maintenance crews on a regular basis. This work frequently requires long working hours, often at night during extreme weather conditions. Visibility is reduced during snow plowing operations by a combination of factors including reflected headlight glare, obscured windows, and blowing snow. These factors vary with the climatic conditions and are often influenced by features of the plow, the vehicle, and its lighting systems. Poor visibility reduces operational safety and contributes significantly to the hazards faced by the operators and motorists. Some states have noted serious accident problems involving snow plows.

Reflected glare from standard headlights, mounted above the snow plow, degrades forward visibility during snow plowing operations because an upward component of light is reflected off airborne snow. This creates the appearance of a white veil, in front of the operator, which further reduces the operator's visibility. Reduced visibility also results for both the operator and other motorists when light powder snow overspills the plow and is caught in the vehicle airstream. The airstream carries the snow to the windshield,

further decreasing the operator's visibility. The snow then continues around the truck body until being caught in the turbulence immediately behind the vehicle. This increases the amount of snow entrained in the vehicle wake. The snow cloud obscures the operator's visibility to the rear and creates a hazardous condition for other motorists. Research is needed to provide for safer snow plowing operations by improving visibility.

The objective of this research is to identify and evaluate equipment improvements to increase visibility for snow plow operators and motorists. In order to achieve this objective, the following tasks are envisioned:

Task 1. Review foreign and domestic literature and contact public agencies and equipment manufacturers to identify means to improve operator visibility during snow plowing operations. The contractor should identify items affecting the operator's visibility including the vehicle (cab design, windshield, wiper/washing systems, defrosting equipment), lighting systems (headlights, tail lights, warning lights), plow equipment and attachments (deflectors, belting), and airstream appurtenances (skirts, wheel covers, foils). Agencies in the United States and Canada should be contacted to determine the types of equipment in use, equipment adaptations, and formal and informal evaluations of equipment performance. The information gathered in this effort should be tabulated and summarized in a manner that reflects the range of conditions experienced in snow plowing operations.

Task 2. From the results of Task 1, identify promising equipment and variations, combinations, and innovations to improve visibility during snow plowing operations. Develop research plans to evaluate the effectiveness of promising equipment. These plans may include field or laboratory tests, simulation, analytical modeling, and surveys. The plans should indicate the approach, duration, costs, and conditions under which the equipment will be evaluated.

Task 3. Prepare an interim report documenting the efforts undertaken in Tasks 1 and 2. Meet with the project panel to discuss the interim report and establish consensus on those items to be evaluated in Tasks 4 and 5 of this project. NCHRP project panel approval of the interim report will be required before proceeding with Task 4.

Task 4. Conduct testing in accordance with the plans approved by the panel. The contractor will be responsible for making all testing arrangements and documenting the test results under various conditions. Test results and their implications shall be reported in quarterly progress reports.

Task 5. Assess the technical, operational, and economic feasibility of equipment tested and make recommendations for approaches to improve visibility during snow plowing operations. Emphasis should be given to the reliability, maintainability, and compatibility of the equipment under the ranges of conditions commonly experienced.

Task 6. Prepare a Final Report which documents the efforts of this project and includes summaries of the test results, feasibility analyses, and equipment recommendations.

AREA 7: TRAFFIC PLANNING

Project 7-12 FY '89

Microcomputer Evaluation of Highway User Benefits

Research Agency: Texas A&M Research Foundation
Principal Invest.: Dr. William F. McFarland
Effective Date: February 1, 1989
Completion Date: December 30, 1993
Funds: $200,000

The objective of this study is to develop a comprehensive, user-friendly, portable microcomputer program capable of using new and updatable support data and the best practical procedures for conducting comprehensive highway user benefit-cost analysis.

Benefit-cost analysis can be used over a broad spectrum of projects and at different levels of detail. The scope of this study should cover highway projects ranging from individual intersection improvements and Transportation Systems Management (TSM) projects to major road upgradings and construction of new roads. Comprehensive life-cycle cost evaluation techniques will be incorporated. The focus of the effort will be directed to analyses at the project level and its immediate area impacts rather than at a highway system level. The project tasks include:

Task 1. Review the literature for procedures used in highway user benefit-cost and related noise and air pollution emission analyses and identify sources of support data for use in the determination of vehicle operating costs, accident reduction benefits, travel-time values, and any other appropriate factors.

Task 2. Assess the support data and procedures identified in Task 1 and select for inclusion in the computer program those most appropriate in terms of their currency, completeness, general use, and ease of updating. In addition, provide a comparative analysis of the selected procedures with those found in the 1977 AASHTO *Manual on User Benefit Analysis of Highway and Bus Transit Improvements.*

Task 3. Develop procedures for updating support data to the current analysis year, and propose default values where appropriate.

Task 4. Develop a preliminary design for the microcomputer program that accurately reflects the anticipated context and degree of user friendliness. The design should address at least the following: screen layouts, menus, input requirements and procedures from the user and from support data sources, modular structure, process flow diagrams, and output formats and compatibility. In addition, develop a preliminary design for a program validation plan, a user's manual, and program documentation report.

Task 5. Prepare and submit to NCHRP an interim report on Tasks 1 through 4. NCHRP approval is required before subsequent tasks are initiated.

Task 6. Develop the comprehensive user friendly software, adapting the selected techniques to microcomputer use. The software should offer at least the following features:

a. Capability to conduct life-cycle cost analysis.
b. Both default values and user-provided data input capability.
c. Procedures for updating support data and parameter values to the analysis year.
d. Informative error messages.
e. Capability to operate on a fully IBM-compatible microcomputer at a reasonable speed, in a portable and commonly available language that does not require additional end user hardware or software acquisition.

Task 7. Validate the software using the validation plan identified in Task 4. The purpose of the validation plan is to ensure that all calculations are performed correctly with adequate checking of data, parameter values, and ranges. Prepare a program validation report that: (a) describes the methodology used in developing the validation plan, (b) provides a description of the test data sets used to validate the computer program, and (c) documents the results obtained by "hand" and by the computer program.

Task 8. Prepare a user's manual, a program documentation report, and a brief, applications-oriented primer on benefit-cost analysis and economic evaluation of highway user benefits.

Task 9. Provide to five states selected by the NCHRP copies of the software, all documentation, and all other necessary materials to implement and test the capabilities of the software. These states will critique the materials provided and transmit written evaluations to the contractor who will make necessary modifications to the program and documentation.

Task 10. Prepare a final report documenting the research effort. It should contain the modified applications-oriented primer; a description of the computer program and its application, including examples; the user's manual; and the program documentation report including the executable program and its source code.

Beta testing of the software has been completed and final revisions made. The documentation has been reviewed and final editing completed.

Project 7-13 FY '92

Quantifying Congestion

Research Agency:	Texas A&M Research Foundation
Principal Invest.:	Dr. Timothy J. Lomax
Effective Date:	March 1, 1992
Completion Date:	February 28, 1994
Funds:	$275,000

In recent years, congestion on streets and highways has grown to critical dimensions in many areas of the United States. This congestion has become a major problem and has many detrimental effects including lost time, higher fuel consumption, more vehicle emissions, increased accident risk, and greater transportation costs.

The concept of congestion as a serious problem has been embraced by the media, the public, policymakers and transportation professionals. However, there is no consistent definition of congestion in terms of a single measure or set of measures that considers severity, duration, and spatial extent. Quantification of congestion on individual facilities, measurement of the rate of change of congestion within an area, and comparison of congestion severity between areas are very difficult. Accurate measures of congestion are needed for analytical purposes, such as system evaluation and improvement prioritization, and for use by policy-makers and the public.

The objective of this project is to develop a cost-effective procedure for accurately and consistently measuring congestion on a roadway facility. Additionally, the procedure should provide methods to evaluate and compare highway system congestion on corridor, subarea, and regional bases and be sensitive to both recurring and incident congestion. The procedure should generate measures that are useful and understandable to policy-makers and the public.

It is anticipated that the research will require the performance of the following tasks:

Phase I:

Task 1. Identify and review definitions of congestion, along with measures and procedures to quantify congestion. Identify potential uses and users of congestion information at the national, state, and local levels.

Task 2. Define criteria that will be used to evaluate candidate measures of congestion. These criteria should consider data issues (e.g., availability, collectability, forecastability, accuracy, and cost) and the relationship between congestion and other transportation issues (e.g., safety, air quality, and user costs).

Task 3. Recommend a definition of congestion and select candidate measures that can be used to quantify congestion and prioritize transportation improvements.

Task 4. Evaluate the congestion measures selected in Task 3 using the criteria defined in Task 2 and recommend the measures to be used. Outline a proposed procedure to obtain these congestion measures.

Task 5. Prepare and submit an interim report documenting the results of Tasks 1 through 4 within 4 months of the initiation of the project. The interim report should include an updated workplan for the remainder of the project. NCHRP approval of the interim report is required before proceeding with Phase II of the project.

Phase II:

Task 6. Evaluate the recommended measures in terms of their intelligibility and usefulness to representative users.

Task 7. Finalize the recommended procedure to obtain the required congestion measures.

Task 8. Validate the procedure through field applications. Demonstrate the consistency of the results through statistical testing.

Task 9. Prepare a user's guide for the procedure. Include information on sampling, accuracy, data collection techniques, costs, uses of outputs, etc.

Task 10. Prepare and submit a final report documenting the results of the project. The user's guide will be an appendix to the final report.

The Phase I interim report and an updated work plan for Phase II are completed. Phase I has resulted in a congestion measurement based on travel time. The Phase I interim report is available on a loan basis. Under Phase II, procedures for collecting data to calculate travel time are being refined using existing data and will be tested in various locations throughout the country.

AREA 8: FORECASTING

Project 8-24A FY '83

Forecasting the Basic Inputs to Transportation Planning at the Zonal Level

Research Agency: COMSIS Corporation
Principal Invest.: David Levinsohn
Effective Date: April 1, 1987
Completion Date: February 28, 1990
Funds: $192,444

Transportation planners forecast travel demand on the basis of anticipated changes in socioeconomic variables such as population, employment, vehicle availability, income, and household size. Errors in the forecasts of these variables can lead to substantial errors in information provided to decision-makers in the evaluation of transportation alternatives. NCHRP Project 8-24 investigated and reported on a portion of this problem area, specifically the preparation of aggregate forecasts for sub-state areas. It examined the sensitivity of the process (and particularly its first step, trip generation) to differences (or errors) in input. However, no analysis of the sensitivity of the process to disaggregation—or variation in aggregation—was performed. This continuation project investigates the availability and utility of methods to produce forecasts for units of sub-county levels of geography, typically traffic zones, either by downward allocation of sub-state forecasts or by direct means.

A problem that frequently arises is that the various techniques used to forecast socioeconomic variables produce significantly different results. Some forecasting techniques produce data that are incomplete or lack sufficient detail for travel estimates and impact assessments.

Recent demographic trends have demonstrated that extraordinary changes in the relationships between population, households, and labor force are not effectively treated in many existing forecasting procedures. Many jurisdictions are encountering more volatile growth patterns that demand a great sensitivity in forecasting methods. Moreover, changing demands on the planning process, including more project-oriented activities, and a frequent need for quick response have changed forecasting requirements.

Planning agencies face three types of circumstances in forecasting for sub-county areas: (1) top-down allocation mandated by the state in cooperation with the localities; (2) competing forecasts for localities, which must be reconciled; and (3) a lack of available forecasts from outside authorities. State and local planners need assistance in choosing techniques to respond to these problems.

Research is needed to document techniques that: (1) have been usefully applied by planning agencies, (2) are applicable at any sub-county level of aggregation, (3) are accurate for intended purposes, (4) are responsive to current planning needs, (5) have well-defined areas of application, and (6) can be implemented and updated by users who do not possess a sophisticated demographic, economic, or statistical background.

The objective of this research is to extend the work documented in *NCHRP Report 266* to describe and evaluate techniques for determining and forecasting the input variables critical for estimating transportation demand at the sub-county geographic level. To accomplish this objective, the following tasks will be performed:

Task 1—Representative methods for allocating or otherwise forecasting socioeconomic variables at the zonal level for large and small urban areas will be selected. At least, the following variables will be considered: population, households, employment by place of residence, workers by place of work, automobiles, and income. Agency sources, such as state DOTs and MPOs, will be used as well as traditional literature sources. The effectiveness of the selected methods will be briefly described relative to extent of use, cost, simplicity, documentation, and software availability.

Task 2—The evaluation criteria to be used in Task 4 for each of the techniques to be considered will be identified.

Task 3—An interim report presenting the findings of the first two tasks will be prepared. This report will provide the basis for panel determination as to whether or not to proceed with the remainder of the research.

Task 4—This evaluation task will expand on the findings of Tasks 1 and 2:

Subtask 4.1—Applicable procedures and techniques for allocation or other forecasting procedures concerning population, jobs, households, vehicle ownership and availability, employment characteristics, income, and such other variables as are necessary for applications in transportation planning at the sub-county geographic level will be described and characterized. The descriptions and characterizations will clarify differences among and appropriateness of each

procedure identified. Constraints or conditions under which each procedure is applied will be listed and described.

Subtask 4.2—For each of the procedures described in Subtask 4.1, discuss conditions of applicability, i.e., where and under what circumstances can such procedures be applied, and how universal or limited is the application.

Subtask 4.3—For each of the procedures described, discuss the types and level of skill necessary to apply the forecasting techniques in transportation planning situations. In addition, effectiveness of performance of these techniques (for example, the adequacy of forecasts for the desired levels of application) will be addressed.

Subtask 4.4—Concise numerical examples illustrating how each method is applied will be provided. The examples will clearly show data inputs and sources, step-by-step procedures of application, and output and its format. The data sources will be completely described and serve as guides to application by local planners (e.g., census data, local surveys, other sources). Where computer application is involved, software references will be provided.

Subtask 4.5—The advantages and disadvantages of each technique will be discussed. The discussion will include but not be limited to data needs, required skills, ease of application, output products, and costs.

Task 5—Research on zonal disaggregation problems will be addressed. The researcher will examine the sensitivity of final estimates of travel demand, i.e., link and line volumes, to changes in values, definitions, and dimensions of socio-input variables at the zonal level.

Task 6—A final report will be prepared documenting the research findings. To the extent practical the report will be prepared in a format suitable for use as a manual of practice for state and local transportation planners, specifically showing the individual steps to be taken in applying each method.

All research is complete and the final report has been published as NCHRP Report 328, "Forecasting the Basic Inputs to Transportation Planning at the Zonal Level."

Project 8-28

Strategic Planning and Management for Transportation Agencies

Research Agency: Ernst & Young
Principal Invest.: Gene Tyndall
Effective Date: June 1, 1987
Completion Date: June 25, 1990
Funds: $180,000

Unlike the period from the end of World War II through the mid-1960's, which was generally characterized by stable economic growth and social and public policy environments, the 1970's and 1980's had been affected by an accelerating pace of change in economic, social, technological, and public policy factors. These factors interacted in ways that required new efforts to properly position organizations in future operating environments. Institutions are needed to develop mechanisms to assure adaptation to the ever-changing environment.

This need for new management systems incorporating more effective means of identifying new directions for organizations and shifts in allocation of resources to implement change was first recognized by the private sector. Strategic planning was initiated by large U.S. corporations in the late 1960's and early 1970's. Because of dissatisfaction with the results of strategic planning when it was conceived and applied only as a *planning function,* many corporations expanded their approach to *strategic management.* In applying strategic management, the *skill* of strategic planning was practiced at all levels of the organization and was integrated into all other management systems to assure the "fit" of strategy to an organization. The expected result was a major improvement in organizational effectiveness.

By the late 1970's strategic approaches had begun to be applied in a few public transportation agencies. Research was now needed to determine the status of strategic planning and management in public sector transportation agencies, to develop an understanding of which approaches are applicable and effective in public agencies, and to identify potential pitfalls. The results of research would provide transportation agencies with guidance to support the successful application of strategic management.

Research has been completed and the final report has been published as NCHRP Report 331, "Strategic Planning and Management for Transportation Agencies."

Project 8-29 FY '91

Travel Estimation Techniques for Urban Planning

Research Agency: Barton-Aschman Assoc., Inc.
Principal Invest.: Mr. William A. Martin
Effective Date: February 15, 1991
Completion Date: February 14, 1993
Funds: $300,000

It has been more than 10 years since publication of *NCHRP Report 187,* "Quick-Response Urban Travel Estimation Techniques and Transferable Parameters." This report and its default data are used widely, in one form or another, in a very large number of transportation studies. It has served as an invaluable travel-data source. However, uncertainty exists as to how much use is still made of the manual techniques presented, and the reader is not referred to the new desktop computer-planning programs. Most importantly, most of the default data are based on data-collection efforts conducted in the 1960s and early 1970s. This brings into question the validity of the various travel parameter values and their variability. The various changes taking place require that the basic methodology of *NCHRP Report*

187 be reassessed to determine the sensitivity of its output to more up-to-date values of input variables.

The objectives of this research are to (1) identify and evaluate current and anticipated trends and issues in travel behavior, urban structure, and the transportation planning tools that will be needed to address them and (2) develop a replacement for *NCHRP Report 187*, with emphasis on small-and medium-sized urban areas. The following tasks are expected:

Phase I: (1) Review and summarize trends in travel behavior, urban structure, related planning issues, and the state of the practice in planning procedures. (2) Identify the travel-related content of the 1990 census and other current data-collection efforts, and analyze the implications of these data on the proposed research and its schedule. (3) Conduct a user survey to determine deficiencies, strengths, applicability, and suggested improvements to *NCHRP Report 187*. (4) Identify which parameters and techniques are in critical need of updating. (5) Prepare an interim report on the results of Tasks 1 through 4 with recommendations for a data-collection and analysis plan, a draft outline of the replacement for *NCHRP Report 187*, and a revised budget to complete the project.

Phase II: (6) Identify and assemble travel-survey data and assess factors affecting transferability and level of accuracy. (7) Organize data, develop the appropriate parameters, and describe appropriate techniques. Address, as a minimum, such issues as parameter transferability between city sizes, urban forms, and socio-economic characteristics. (8) Prepare a final report to include recommended practice and updated parameters that will serve as a replacement to *NCHRP Report 187*. As part of the preparation of the final report, conduct a comprehensive error and consistency check of all techniques, formulations, computations, and transferable parameters and other data contained within the report and accomplish necessary adjustments and corrections.

All research has been completed and the draft final report is being reviewed by the project panel. The final report should be published by mid-1994.

Project 8-30 FY '93

Characteristics and Changes in Freight Transportation Demand

Research Agency:	Cambridge Systematics, Inc.
Principal Invest.:	Dr. Herbert Weinblatt and Dr. Harry Cohen
Effective Date:	December 15, 1992
Completion Date:	March 15, 1995
Funds:	$500,000

Many changes are taking place in the United States and abroad that profoundly affect freight transportation demand. These include changes in demographics, energy availability, cost, production, industry and logistics practices, and U.S. roles in the global economy. Such changes are affecting the type of freight moved, its density and packaging, its origin-destination patterns, and its requirements for delivery. The need has been recognized for comprehensive freight policies at both the state and national levels, but research is needed first to address critical issues. Further study is necessary to (1) better understand the characteristics of freight transportation demand, (2) assess trends in the characteristics of freight, (3) identify the key factors that promote changes in domestic freight transportation demand (including the domestic component of international movements), and (4) determine the interrelationships between freight transportation demand and supply. This research is needed to support the development of a process for forecasting future freight transportation demand. It would also provide critically needed background information for the analyses of (1) modal competition and coordination, (2) the influences of institutions, investments, and policies, and (3) the impacts on transportation infrastructure, safety, operations, and financing.

The objectives of this research are to examine the changing character and composition of U.S. freight transportation demand across all modes and to develop a process to effectively forecast future demand. This will involve macro-level analyses over time of the characteristics of freight transportation demand and its changes, the key economic, technological, political, and social factors that contribute to those changes, and the interaction effects between freight transportation demand and system supply.

To accomplish this objective, a three-phased effort is envisioned. The first phase will characterize freight transportation demand in measurable and relevant terms, summarize current understanding of the key factors that affect, or are likely to affect, freight transportation demand, and determine the interrelationships between the key factors and freight demand characteristics. The second phase will conceptualize a process for forecasting future freight transportation demand and will assess the feasibility of this process, considering the availability of information, the nature of changing practices, the ability to monitor future conditions, and the complexity of the interactions between actors. The last phase will focus on the development, enhancement, and documentation of the process including the formulation of prototype models.

Phase I: Summarize Freight Transportation Demand Information and Trends. (1) Identify the most critical questions about freight transportation demand at the federal, state, and local levels through (a) agency interviews, (b) a review of modal policies and legislative initiatives, and (c) a review of past freight studies. Also, identify the methods that have been used to address these questions and assess the extent to which they have been integrated into transportation system planning. (2) Establish an advisory group of at least 8 recognized experts in freight transportation logistics, operations, and modeling from the public and private sectors, as well as academia, to provide insights into the impacts of changing manufacturing, shipping, packaging, carrier operation, and marketing practices. The advisory group will be expected

to provide feedback on the various working papers and to participate in the planned workshop. (3) Identify the key characteristics of freight transportation demand (for individual modes and across modes) and specific measures for each. Examples of characteristics are commodity types, shipment size and density, shipment distance and frequency, delivery requirements, and origin-destination patterns. Assess the viability of existing databases, anticipated new data and classification schemes to support the measures of freight transportation demand characteristics. (4) Identify the key economic, social, political, technological, environmental, or other factors that influence the characteristics identified in Task 3. Identify specific measures for each key factor and assess the viability of existing and anticipated databases and classification schemes to support future freight transportation demand forecasting. Critical current and emerging factors should be highlighted and their consequences cited. Examples of current key factors include the emergence of a global economy and new regional blocks, changing industry production practices, changes in distribution techniques and technologies (e.g., just-in-time delivery, electronic data interchange), and regulations. (5) Identify trends and relationships between freight transportation demand characteristics identified in Task 3 and the key influencing factors identified in Task 4 and consider the influences of transportation supply on the trends and relationships. The qualitative and quantitative trends or relationships identified are expected to serve as a basis for forecasting freight transportation demand and to support other research. The findings of this task should be succinctly summarized in an interim report that will be submitted to the NCHRP panel and advisory group for review.

Phase II: Conceptualize Freight Transportation Demand Forecasting Process. (6) Outline a process for forecasting freight transportation demand, which will include procedures to identify emerging influences and scenarios, relate the influences of transportation system supply, and apply econometric, network simulation, or other appropriate models to assess the impact of future conditions on freight transportation demand. Emphasis should be focused on developing an effective, state-of-the-art process considering freight characteristics, the key influencing factors, the relationships defined in Task 5, and the types of questions that need to be answered. The applicability and adaptability of past approaches and models for forecasting freight transportation demand should be determined. (7) As part of the freight transportation demand forecasting process conceptualized in Task 6, establish systematic procedures for analyzing how emerging factors and other external changes can shape the characteristics of freight transportation demand. These "future mapping" procedures should be oriented for use by decision makers to address the types of questions identified in Task 1. The future mapping procedures should identify the *critical* pieces of information required and the potential range of outcomes for freight transportation demand analyses. (8) Describe the application of the forecasting process to address typical freight transportation questions in the context of at least two case study situations. One situation should focus on a national-level application and the second on a state- or regional-level application. The contractor should assess the availability of data, the reliability of the procedures, the uncertainty associated with forecasts, the changing importance of factors, the applicability to different agencies, and the range of issues that can be addressed. (9) The contractor will prepare a second interim report that will fully describe the conceptual freight transportation demand forecasting process, the future mapping procedures, the case study applications, and the feasibility assessment. The contractor will organize a workshop forecasting freight transportation demand to provide an opportunity for discussion of the findings of Phase I and the forecasting process conceptualized in Phase II. During the workshop, participants will validate the characterization of past and emerging freight transportation demand trends and relationships and thoroughly critique the conceptualized freight transportation demand forecasting process. The workshop should be structured to include a step-by-step demonstration of the process for the case study situations. The workshop participants will be expected to evaluate the feasibility of the process in terms of data availability, process integrity, forecast sensitivity, and other aspects. The contractor will be expected to prepare a comprehensive summary of the deliberations and conclusions of the workshop and to incorporate these as appropriate into subsequent project efforts and reports.

Phase III: Refine, Develop, and Document Forecasting Process. (10) If the workshop participants conclude that it is feasible to forecast future freight transportation demand, develop prototype models for use in the forecasting process conceptualized in Phase II. The prototype models should be developed considering the availability of data, the trends and relationships identified in Task 5, and the functionality and adaptability of past forecasting approaches and models. Prototype models should be developed for broad applicability in addressing the range of questions faced by federal, state, and local agencies. Test the prototype models against the case study scenarios previously developed. (11) Develop an easy-to-use guidebook for the application of the process and models. The guidebook should identify the key information needed for scenario assessments, describe methods to collect this information, outline the steps in the forecasting process, and apply the prototype models. (12) Recommend an implementation strategy appropriate for federal, state, and local agencies to adopt the freight transportation demand forecasting process. The strategy should reflect the requirements for Intermodal Management Systems in the Intermodal Surface Transportation Efficiency Act and other applicable policies. (13) Prepare a final report that includes recommended work plans with cost estimates for the second research stage to fully develop the freight transportation demand forecasting process.

The research is continuing after panel approval of the Phase I interim report.

Project 8-31 FY '93

Long-Term Availability of Multimodal Corridor Capacity

Research Agency: The Urban Institute
Principal Invest.: Mr. William A. Hyman
Effective Date: January 4, 1993
Completion Date: January 6, 1995
Funds: $285,000

The objectives of this research are to evaluate the scope and severity of current and future capacity problems and constraints on transportation corridors, and to recommend strategies to ensure the long-term availability of multimodal corridor capacity.

To meet the objectives, a two-phased project is being conducted. The purposes and the tasks associated with each phase are described as follows.

Phase I has two purposes: One is to develop an analytical methodology, including a manual, for performing multimodal corridor capacity analysis. A second purpose is to evaluate completed and ongoing studies and data on current and future multimodal corridor capacity. Phase I will require at least the following tasks: (1) Review the literature and identify and develop definitions of terms appropriate for the key issues in this study. The terms shall include but not be limited to (a) multimodal corridor, (b) capacity, (c) congestion, and (d) long term. (2) Identify, evaluate, and summarize completed and ongoing studies of corridor problems, capacity preservation and expansion strategies, methods of corridor administration, and shipper, carrier, and traveler responses to congestion. (3) Develop a multimodal corridor capacity analysis manual that will serve as the analytical framework for the corridor analyses to be conducted as part of this research project. Based on the findings of Tasks 1 and 2, develop a typology of transportation corridors including, but not limited to, severity of traffic problems, facility expansion constraints, and feasible multimodal transportation alternatives. Using the analytical framework of the corridor capacity analysis manual and the typology, develop a detailed work plan for the research to be conducted in Phase II. The plan should include a proposed methodology for quantifying congestion and total corridor capacity both for the present and for the long-term future. As a minimum, the plan should provide information to produce the following: (a) identification of the constraints on current and future expansion of transportation corridor capacity, (b) identification of various responses by transportation users and providers to corridor congestion, (c) quantification of the impact of those responses by transportation users and providers on corridor congestion, (d) characterization of the competition for corridor capacity between various users and providers, and (e) a summary of the potential contributions of nontraditional solutions to corridor congestion. (4) Prepare a Phase I interim report documenting the findings of Tasks 1 through 3 and providing a detailed work plan for Phase II. Meet with the NCHRP project panel to present the interim report. Research on the remaining tasks shall not be initiated until the interim report has been approved by the NCHRP project panel.

Phase II. The purpose of this phase is to characterize the scope and severity of current and future capacity problems and the constraints on expansion in multimodal corridors, and to recommend strategies for preserving long-term capacity. At least the following tasks will be required: (5) Execute the approved work plan for Phase II. (6) Analyze the results to (1) develop the best possible estimate of the number and location of multimodal corridors nationwide where capacity problems exist or are expected soon, and (2) formulate recommendations for strategies necessary to ensure the long-term availability of multimodal corridor capacity. (7) Prepare and submit a final report documenting the entire research effort.

Task 1 is complete and substantial work has been accomplished on Tasks 3 and 4. A first draft of the "Multimodal Corridor Capacity Manual" is being reviewed by the project panel.

Project 8-32 FY '94

Workshop on Multimodal Transportation Planning Research Needs

Research Agency: Transportation Research Board
Principal Invest.:
Effective Date: January 12, 1993
Completion Date: December 31, 1993
Funds: $60,000

An announcement for a TRB Conference held in Seattle, Washington, July 19-22, 1992, on Transportation Planning, Programming, and Finance includes the following statement of purpose: "Many changes have taken place that have created new challenges for planning and programming decisions in the 1990's especially the impacts of the recently passed surface transportation legislation that will greatly impact the planning and programming area. These challenges include (1) an increasing emphasis on maintenance and rehabilitation of an aging infrastructure versus new facility expansion; (2) a growing concern with urban and suburban growth and congestion and the appropriate mix of management and investment actions needed to address it; (3) the impact of the new Clean Air Act and other environmental considerations; (4) the new Surface Transportation Act including major changes to the federal program structure, federal/state matching ratios for funding, and the definition of the federal aid highway system; (5) funding pressures at all levels of government and the resulting interest in private sector funding sources; and (6) greater emphasis on multimodal issues."

In view of these issues, there is a pressing need to improve processes for transportation planning, programming and fi-

nancing. Research is needed to identify approaches that can be used to address these aspects reflecting each area's particular institutional structure, programming process, system needs, financial resources, and funding mechanisms.

The objectives of the project will be to (1) review the emerging issues affecting planning and program decisions, e.g., accommodating environmental criteria and implications of the recent clean air and wetlands requirements; (2) assess current and new approaches to programming and planning including institutional and technical aspects; (3) determine the steps required to address emerging issues; and (4) develop a research action agenda. An important element in this research will involve convening a workshop of transportation leaders to addressing the issues in an effective manner.

The workshop was held on November 1 to 3, 1993, resulting in a research agenda that will be presented to the AASHTO Standing Committee for Research for its consideration of research projects for the NCHRP.

AREA 9: BITUMINOUS MATERIALS

Project 9-6(1) FY '85 and FY '90

Asphalt-Aggregate Mixture Analysis System (AAMAS)

Research Agency: Brent Rauhut Engineering, Inc.
Principal Invests.: Harold L. Von Quintus
Effective Date: January 5, 1987
Completion Date: June 4, 1990
Funds: $675,000

The highway community recognizes the need for improved procedures and analysis systems for the design of asphaltic concrete pavement mixtures that will be resistant to heavy truck loads, the use of higher tire pressures, and the wide extremes of climate. Such systems should optimize the selection, proportioning, and processing of asphalt binders and aggregate materials to produce pavements resistant to all forms of distress.

This research developed an asphalt-aggregate mixture analysis system (AAMAS) for the design of optimum paving mixtures based on performance-related criteria. These criteria encompass a wide variety of failure modes, e.g., fatigue cracking, thermal cracking, permanent deformation, moisture damage, age hardening, etc. The AAMAS is capable of accommodating conventional asphalt binders, modified asphalts, mixture modifiers, and the range of aggregate materials used in the United States. It is also capable of evaluating the mixtures under conditions analogous to those found in service, including a wide range of climate, traffic, and age factors. Excluded are open-graded friction courses and drainage layers. The analysis system includes such elements as the preparation of test specimens, conditioning of the specimens, testing the specimens, criteria for mixture selection, and a step-by-step mixture design procedure.

The research has been completed. The final report has been published as NCHRP Report 338, "Asphalt-Aggregate Mixture Analysis System (AAMAS)." Four workshops were conducted to introduce AAMAS to state highway agencies in the four AASHTO regions. Asphalt research under the Strategic Highway Research Program is building on the research accomplished in this project.

Project 9-7 FY '93

Field Procedures and Equipment to Implement SHRP Asphalt Specifications

Research Agency: Brent Rauhut Engineering
Principal Invest.: Ronald Cominski
Effective Date: April 1, 1993
Completion Date: September 30, 1996
Funds: $900,000

Researchers in the asphalt area of the Strategic Highway Research Program (SHRP) are fulfilling their goals of producing performance-related specifications for asphalt binders and mixtures. These specifications will be accompanied by specific procedures and equipment for applying the SHRP mixture design and analysis system. The proposed specifications, which incorporate findings from a number of previous studies including NCHRP Project 9-6(1), "Asphalt-Aggregate Mixture Analysis System (AAMAS)," are expected to significantly advance asphalt technology, by relating improved asphalt binders and mixture design with actual field performance.

Interest in products from the asphalt area of SHRP is growing throughout the nation, and AASHTO member departments are actively gearing up for SHRP implementation. The AASHTO Task Force on SHRP Implementation has targeted SHRP's asphalt products as one of their early priorities. Members of the AASHTO Highway Subcommittee on Materials are evaluating more than 20 specific products in the asphalt area. A pooled-fund study is being formed to assist states in purchasing the necessary laboratory test equipment. To fully implement SHRP recommendations, however, industry must be involved and will need the knowledge and tools to comply with the new requirements. User-producer groups are forming on a regional basis, involving highway agencies, contractors, and materials manufacturers and suppliers. Information presented to these groups by SHRP researchers and staff is encouraging awareness of and support for these new systems and specifications.

Significant improvements in binders, test equipment and procedures, analysis of test results, and specifications will provide mixtures for greater performance. However, to realize these improvements, highway agencies must change the way asphalt pavement materials are designed and specified, and the asphalt mixtures placed and compacted on the roadway must comply with the specifications. How can this be ensured? What specific Q/C Q/A equipment and procedures

must be used at the asphalt plant and the paving site, and what statistical tolerances are necessary on these procedures? What controls must be placed on the asphalt binder, the aggregates, any additives or modifiers, the process, and the final mixture? How can appropriate compaction be assured? How often and by whom should these Q/C Q/A procedures be accomplished? What training is needed and who will be qualified to take the mixture design and analysis system from the laboratory to the field?

Field control procedures are being developed under the SHRP A-001 contract to assist field technicians in adjusting mixture design and monitoring production; however, this effort is limited to the adaptation of previously developed steps. Needed is a major research effort focusing specifically on field implementation of SHRP asphalt specifications.

The objectives of this research are: (1) to establish comprehensive procedures and, if required, develop equipment for quality control/quality assurance at the asphalt plant and laydown site to ensure that asphalt pavements meet the SHRP performance-related specifications and (2) to develop a framework for a training program for qualifying technicians to accomplish the Q/C Q/A field procedures developed.

Accomplishment of the objectives will require at least the following tasks: **Phase I** — (1) Review and analyze SHRP performance-related specifications and research results, including SHRP recommendations for field control procedures, as well as data from SPS-9 pilot projects. (2) Review and evaluate other applicable research activities in asphalt mixture Q/C Q/A. (3) Review Q/C Q/A issues and relationships in related industries or industries with similar control or production procedures to identify applicable concepts. (4) Recommend the appropriate level of control, i.e., tests or other measures, for the quality of materials delivered to the asphalt plant, including asphalt cement, aggregate, modifiers, and additives. (5) Propose a statistically based experimental plan to collect field data that can be used to develop procedures to verify, accept, and control the asphalt mix. Verification will ensure the mix produced by the plant and laid in the field meets the SHRP performance-related specifications. (6) Submit an interim report that presents the results of Tasks 1–5 and describes in detail the work proposed for the remaining tasks.

Phase II — (7) Conduct the series of field experiments approved in Phase I. (8) Based on data collected in Task 7, establish the allowable tolerances and variabilities of the various test results. The test procedures must produce results in a timely manner. (9) Based on the results of Task 8, identify the need for modified or additional field testing equipment, and, if needed, develop the equipment in accordance with NCHRP approval.

Phase III — (10) Finalize Q/C Q/A procedures. These procedures shall include a family of statistically based sampling and test plans appropriate for SHRP mixture design levels for various levels of service (based on traffic volume). (11) Develop guidelines using Q/C Q/A procedures that define the circumstances when mix adjustments, which may be made in the field, are applicable versus those circumstances that require a complete new mix design. (12) Develop guidelines for implementation of these research results. (13) Design a framework for a training program for qualifying technicians. (14) Submit a final report documenting the entire research effort.

Research is underway and the consultant is working on Tasks 1, 2 and 3. The consultant is reviewing options if the SPS-9 projects are not built in a time frame to meet project objective.

Project 9-8 FY '94

Designing Stone Matrix Asphalt Mixtures

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	(24 months)
Completion Date:	
Funds:	$500,000

Stone Matrix Asphalt (SMA) is defined as a gap-graded aggregate-asphalt hot mix that maximizes the asphalt cement content and coarse aggregate fraction. This provides a stable stone-on-stone skeleton that is held together by a rich mixture of asphalt cement, filler, and stabilizing agent.

SMA was developed in Europe and appears to have significant potential as a durable, rut resistant, long-life pavement layer. Therefore 12 state highway agencies have recently placed SMA in an attempt to combat distresses in asphalt pavement caused by high traffic volume, heavy wheel loads, and high tire pressures. However, although SMA in itself may have the potential to combat such distresses, it should not be applied as a panacea on top of an inadequate pavement structure.

The approach to date in the United States has been to duplicate SMA mixtures developed in Europe, using domestic materials, equipment, and asphalt-industry expertise. More than 20 SMA pavement projects have been constructed successfully in the U.S. and are now being monitored for their performance.

The FHWA, state transportation agencies, and industry have identified the need for better definition of the currently specified components and properties for SMA mixtures and the need to consider new test procedures. Better information is needed regarding type and amount of stabilizer(s), required compactive effort, and mixture volumetrics for design and placement. New tests may measure properties such as durability, rut resistance, and moisture susceptibility.

The ultimate goal of this research is to develop objective procedures for the use of SMA. Accomplishment of this goal is expected to require several phases of research. The objectives of this first phase of the research are (1) to define the materials and the properties of the materials and mixtures required in SMA to maximize durability and rut resistance

and (2) to recommend an SMA-mixture design procedure (include water sensitivity).

The research will include as a minimum the following tasks:

Task 1. State of the Art. Review and analyze current laboratory design procedures, specifications, and construction practices for SMA. This review will include and expand on the activities of the FHWA's SMA Technical Working Group.

Task 2. Critical Material and Mixture Properties. Based on the above information and the experience of the researchers, identify and evaluate material and mixture properties critical to the performance of SMA. The researchers are expected to identify how changes in aggregate type, shape, and grading; fraction passing the #200 sieve; stabilizers; and asphalt cement affect mixture volumetrics, durability, and performance of SMA.

Task 3. Selection of Laboratory Tests. In conjunction with Task 2, determine the applicability of current test methods for assessing the performance of SMA mixtures. Recommend tests (existing, modified, or new) to predict durability, performance, and moisture susceptibility of SMA mixtures. It is anticipated that existing methods and equipment can be used with some modifications to accomplish this task.

Task 4. Interim Report. Submit an interim report within 7 months after initiation of the research. The interim report shall summarize the accomplishments of Tasks 1—3 and include a tentative mixture design procedure and a detailed work plan for the remaining tasks. NCHRP approval of the interim report and the proposed plan will be required before proceeding with the remaining tasks.

Task 5. Mixture Design Procedure. Evaluate and modify as appropriate the proposed mixture design procedure. The procedure must include specimen fabrication, test methods, mixture design criteria, sample size, and the number of replicates. Evaluate the sensitivity and repeatability of the proposed procedures.

Task 6. Mixture Analysis. Refine the mixture design procedure through a test program that includes a range of aggregate gradations, mineral fillers, and stabilizers. Mixture properties such as minimum voids in the mineral aggregate, voids in the total mixture, minimum effective asphalt content, and moisture susceptibility will be analyzed.

Task 7. Final Report. Prepare a final report documenting the entire research effort.

AREA 10: SPECIFICATIONS, PROCEDURES, AND PRACTICES

Project 10-13 FY '79 and FY '82

Ultrasonic Measurement of Weld Flaw Size

Research Agency:	The Welding Institute (England)	
Principal Invest.:	Timothy J. Jessop	Peter J. Mudge
Effective Date:	July 1, 1979	October 1, 1982
Completion Date:	October 31, 1981	August 31, 1985
Funds:	$126,000	$250,000

The overall objective of this study was to identify or develop, and to validate, ultrasonic testing procedures for accurate measurement of flaw dimensions that will allow fracture-mechanics analysis.

This study was addressed primarily to evaluation of complete joint penetration groove welds containing planar-type flaws such as cracks or incomplete fusion.

In the first phase of research, laboratory tests on intentionally flawed specimens were used to determine the applicability and limitations of AWS D1.1-80 ultrasonic testing procedures for measuring the dimensions of flaws in welds. Phase I also included an evaluation of procedures that extend available ultrasonic techniques and have a potential for accurate measurement of flaws typically found in structural weldments. The accuracy, precision, reliability, and reproduceability of the time-of-flight and probe movement techniques were investigated.

The final report on Phase I has been published as: NCHRP Report 242, "Ultrasonic Measurement of Weld Flaw Size."

The Phase II objectives were to develop recommendations for applications of tandem-probe techniques for the characterization of vertical, planar defects and to refine the time-of-flight system for sizing through-thickness flaw dimensions.

The research in this second phase included a review of all relevant literature and test data in order to develop a more realistic means of assessing vertical planar defects within the framework of the currently used AWS D1.1 code. Time-of-flight equipment was designed and assembled and subsequently evaluated in the laboratory in order to establish the accuracy of the equipment in measuring through-thickness dimensions for a variety of weld defects. Finally, a field evaluation of the equipment was performed in order to establish its accuracy and applicability, as well as to provide recommended procedures for use.

The Phase II final report will not be published, but copies of the agency's final draft report were distributed to NCHRP sponsors in early 1989. Copies are available on a loan basis from the NCHRP (see final page of this document for ordering information).

Project 10-17 FY '81, '87 and '92

Use of Antistripping Additives in Asphaltic Concrete Mixtures

Research Agency:	David G. Tunnicliff
Principal Invest.:	David G. Tunnicliff
Effective Date:	March 1, 1981
Completion Date:	June 1, 1994
Funds:	$676,335

There is an increasing awareness of asphaltic concrete pavement failures caused by stripping of asphalt cements from the aggregates. Consequently, more highway agencies are requiring the use of antistripping additives. If an additive is used when it is not needed, the added cost is an economic

waste. If an additive is used ineffectively, the pavement may require early and costly maintenance and/ or rehabilitation. Highway agencies need information on the selection, effectiveness, and use of antistripping additives.

The long-term general objective of this research is to provide information on the selection and use of antistripping additives (materials used to improve the asphalt-aggregate adhesion in asphaltic concretes). The specific objective of the initial phase was to develop guidelines for the incorporation of antistripping additives in asphaltic concrete paving mixtures considering the influence of such factors as (1) storage and handling of the additives, and (2) stability and effectiveness of additives during mixing and storage of asphaltic concrete.

Research has been completed on the initial phase with accomplishment of the objectives. The test method for measuring the potential for moisture damage in asphalt concrete pavements described in NCHRP Report 246 was modified to reduce test time and control the degree of saturation. The modified test method was used to evaluate effects of storage and handling of asphalt aggregate mixtures on antistripping additives. The project report for the initial phase has been published as: NCHRP Report 274, "Use of Antistripping Additives in Asphaltic Concrete Mixtures." The report contains a state of the art in use of antistripping additives in asphaltic concrete paving mixtures and guidelines for use of such additives.

A precision study has been completed for the test method developed in the initial phase. That test method and precision study have been approved by ASTM Committee D-4 and adopted as ASTM D 4867, "Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures."

In the field evaluation phase, nineteen test sections were included in asphalt paving projects in eight states. Each project contained a control section without additive and a test section including additive. Materials from these projects have been tested. Field cores have also been taken and tested. This has revealed little evidence of moisture damage because the test projects have not been wet enough nor are they old enough for moisture damage to have occurred. The principal investigator has submitted an "Interim Report" on the field evaluation phase and recommended that field observations be continued on these test sections until original objectives are satisfied. To accomplish this and fully conclude the research, a continuation phase was initiated in September 1992.

The final phase of the research project is underway. Condition surveys have been completed and cores have been taken. Results are being compiled and analyzed.

Project 10-20 FY '81, FY '83, and FY '85

Elastomeric Bearings Design, Construction, and Materials

Research Agency:	University of Washington		
Principal Invest.:	Dr. C. W. Roeder Dr. J. F. Stanton		
Effective Date:	2/1/81	6/1/83	6/1/86
Completion Date:	6/30/82	11/30/86	5/31/89
Funds:	$74,715	$150,000	$150,000

The overall objective of this project was to develop specifications for unconfined, plain and reinforced elastomeric bridge bearings.

The findings of Phase I of Project 10-20 were published as: NCHRP Report 248, "Elastomeric Bearings Design, Construction, and Materials," and included recommendations for improved specifications for unconfined, plain and reinforced elastomeric bridge bearings. These recommendations were based on currently existing information. In 1985, AASHTO adopted many of the recommendations of the Phase I research, substantially revising the provisions for elastomeric bearings in the AASHTO *Standard Specifications for Highway Bridges.*

The objective of the second phase of research was to develop a more sophisticated specification for special applications and to improve the simplified provisions recommended in Phase I. The Phase II research included testing and evaluation of bearing compression, rotation, shear, stability, fatigue, and low temperature behavior. Recommendations for a more rational bearing specification were included in the project report. The findings of Phase II of Project 10-20 were published as NCHRP Report 298, "Performance of Elastomeric Bearings."

The objectives of the third phase of research were to resolve design procedures for special applications of unconfined elastomeric bearings and to provide a critical state-of-the-art review of design and construction procedures for pot bearings. The Phase III research included additional experimental work on the low temperature behavior of unconfined elastomeric bearings in order to assist in the development of recommended manufacturing tolerances, bearing prequalification procedures and tests, and improved design specifications. The findings of the unconfined bearing research are contained in NCHRP Report 325, "Low Temperature Behavior and Acceptance Criteria for Elastomeric Bridge Bearings." The pot bearing state-of-the-art review is summarized in NCHRP Research Results Digest 171, "Pot Bearings and PTFE Surfaces."

Project 10-20A FY '88

High-Load, Multi-Rotational Bridge Bearings: Design, Materials, and Construction

Research Agency:	University of Washington
Principal Invest.:	Drs. C. W. Roeder and J. F. Stanton
Effective Date:	August 21, 1989
Completion Date:	September 30, 1993
Funds:	$265,398

In recent years, specialty bearings have been introduced for use in highway bridge construction. Prominent among

these are the high-load multi-rotational (HLMR) types of bearings.

Current specifications for HLMR bearings have been developed from industry standards and vary widely throughout the United States. There is a need for a broad range, generic specification that reflects the best of current practice and will ensure long life, high quality, reliable bearings.

Although there is a proliferation of HLMR bearing specifications, many basic questions remain unanswered. These include questions related to: (1) the performance characteristics of such bearings subjected to induced eccentric loading while under rotation; (2) the apparent loss of full performance capabilities; (3) the long-term durability of certain materials and bearing configurations; and (4) the disparities between domestic and foreign design procedures and materials applications.

There is also inadequate information available to the bridge engineer providing concise guidance on the selection of an appropriate bearing for a specific design situation. Therefore, a selection guide is needed which will inform bridge engineers of the relative performance features for HLMR and conventional bearings used in new bridge designs in the United States.

The objectives of this research are to develop (1) a bearing selection guide for all bearings currently used in new bridge designs in the United States and (2) specifications for high-load multi-rotational bearings that can be recommended to AASHTO for consideration for adoption. Base-isolation bearings are not intended to be included in this research. PTFE slide units associated with high-load multi-rotational bearings shall be considered.

The research will include the following tasks:

Task 1. Review current domestic and foreign codes of practice, research findings, and performance data on all bridge bearings within the scope of the bearings selection guide that will be developed under Task 2. The emphasis of this survey, however, should be placed on the HLMR bearings that will be covered under the specification to be developed in Task 3.

Task 2. Develop a draft bearing selection guide for all bearings currently used in new bridge designs in the United States, with the exception of base-isolation bearings.

Task 3. Develop draft specifications for the design, materials, and construction of HLMR bearings in a format suitable for consideration by AASHTO.

Task 4. Prepare an interim report which includes the following: (1) a summary of the findings from Task 1; (2) the draft selection guide and draft specifications; (3) a prioritized list of laboratory tests, possibly supplemented by field observations, that may be required to complete the selection guide and specifications; and (4) a recommended test program of the highest priority research needs that can be accomplished within a funding level of $150,000.

Task 5. Perform laboratory tests. As a minimum, these tests shall examine the moment-rotation characteristics and lateral load capacity for all types of HLMR bearings, and sealing requirements and internal lubrication for pot bearings.

Task 6. Revise the draft selection guide to incorporate the findings from Task 5.

Task 7. Revise the draft specifications for HLMR bearings to incorporate the findings from Task 5.

Task 8. Submit a final report documenting all research and presenting the recommended bearing selection guide and specifications.

Research on the project was completed in 1992 and revised final draft of the final report has been submitted. The final report includes proposed specifications in load and resistance factor design (LRFD) format using customary U.S. units of measurement. Additional work is being conducted to prepare the specifications in LRFD format with SI units, as well as in allowable stress design (ASD) format with customary U.S. units. A decision on publication of the final report will be made when the supplemental specifications have been reviewed.

Project 10-22 FY '82

The Performance of Weathering Steel in Bridges

Research Agency:	Sheladia Associates, Inc.	
Principal Invest.:	Dr. Pedro Albrecht	
Effective Date:	April 1, 1982	July 23, 1984
Completion Date:	February 29, 1984	August 31, 1987
Funds:	$74,851	$120,699

The objectives of the first phase of research were (1) to assemble a systematic body of information on the performance of weathering steel, and (2) to document and evaluate the current state of practice.

The first phase of research has been completed, and the final report published as: NCHRP Report 272, "Performance of Weathering Steel in Bridges."

The second phase of research had as its specific objectives to fatigue test 8-year weathered A588 transverse stiffener specimens under constant loading in air and aqueous environments, and to develop practical guidelines for design, construction, maintenance, and rehabilitation of weathering steel bridges.

Research on the second phase is also complete and has been published as NCHRP Report 314, "Guidelines for the Use of Weathering Steel in Bridges."

Project 10-25A FY '85

Instantaneous Determination of Water-Cement Ratio in Fresh Concrete

Research Agency:	Wiss, Janney, Elstner Associates, Inc.
Principal Invest.:	William G. Hime
Effective Date:	June 1, 1985
Completion Date:	February 15, 1990
Funds:	$300,000

This project investigated the application of analytical instrumentation and procedures to the rapid determination of water:cement ratio of fresh concrete. Attempts were made to develop a single "probe" that could be inserted into the fresh concrete and uniquely provide its water:cement ratio. The probe involved the use of specific ion electrodes capable of measuring the concentration of ions dissolved from the cement by the concrete mix water. Because of "poisoning" of the electrodes and occasional unexplained variances, this approach was abandoned. The work, however, suggests that such an approach may prove fruitful as instrumentation improves.

Other procedures for the separate determinations of water and cement were, however, pursued and found capable of providing data for calculation of water:cement ratio within ten minutes. Water is determined by a microwave technique employing a special ashing block assembly that allowed a determination of total water in one minute. The water determined includes that due to aggregate absorption, but the sample is chosen to minimize aggregate absorption to a level that can generally be ignored.

A second method involving use of a bromide specific ion electrode does not require a power source and its use could improve the Kelly-Vail procedure often used for water content determinations. This method primarily provides a net water content.

Cement is determined by a specially developed colorimetric procedure for soluble silica.

Research is complete. Research Results Digest No. 174, "Determinations of Water:Cement Ratio in Fresh Concrete," has been published, and it summarizes the research effort. The agency's complete final report was also distributed to all state DOTs. The agency's final report is available to others on loan or for purchase on request to the NCHRP.

Project 10-26A FY '84

Performance-Related Specifications for Hot-Mix Asphaltic Concrete

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. David A. Anderson and Dr. David R. Luhr
Effective Date: January 6, 1986
Completion Date: September 30, 1989
Funds: $250,000

Performance-related specifications are those that require tests or other control measures on materials and construction, the results of which correlate to a known degree with performance of the completed highway facility. The need to reduce sampling and testing costs has required a continuing examination of specifications by the states and the Federal Highway Administration. These examinations have convinced many of the need to identify effective performance predictors and their variability limits, to develop specifications based on these predictors, and to apply cost-effective sampling and testing plans to assure compliance.

A promising approach toward establishing performance predictors is to recognize the establishment of design factors as predictors of ultimate performance and then to use materials and construction testing as a means to ensure adequate compliance with or achievement of the design factors. As an example, for asphaltic concrete construction, stiffness (elastic modulus) and tensile strain would be possible design factors, while asphalt content and percent air voids would be possible materials and construction test data.

Although the relationships among materials and construction tests, design factors, and performance are of primary interest, the relative impact of other factors cannot be ignored. Factors such as quality of construction, environment, and reliability of testing techniques are among many that can have significant effects.

Establishing or verifying the causal relationships and the sensitivity of these relationships among performance, design factors, and test data requires first the development of an overall conceptual model or framework. Once the concept has been formulated, the variables and data needs must be identified. With the data, previously established or conceptual relationships can be verified and further analyzed for the predictive sensitivity of each variable and its reliability. The ultimate purpose will be to develop materials and construction specifications that relate to the actual performance of the facility. This process will be an iterative one, but careful planning will produce meaningful results promptly and with minimum waste.

This study identified the relationships between materials and construction test data and the performance of hot-mix asphaltic concrete. Causal relationships among performance, design factors, and test data needed verification with the ultimate aim of formulating specifications that directly (or through identifiable indirect means) relate, within acceptable tolerances, to the performance of hot-mix asphaltic concrete in a pavement cross-section.

Research has been completed, and the final report has been published as NCHRP Report 332, "Framework for Developing Performance-Related Specifications for Hot-Mix Asphaltic Concrete."

Project 10-27 FY '84

Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. Robert Lytton
Effective Date: September 17, 1984
Completion Date: August 31, 1989
Funds: $449,519

An increasing responsibility of highway and transporta-

tion agencies is the maintenance, rehabilitation, and management of highways that have been built. Particularly with regard to asphaltic concrete pavements, this requires the use of efficient and economical methods for determining the structural properties of existing pavements. Use of nondestructive testing (NDT) data with associated analysis methods is an excellent tool for determining these pavement structural properties. Several types of NDT equipment were evaluated, and the falling weight deflectometer was judged to be preferred for use on either a network or project basis. An analysis procedure to quickly back-calculate pavement layer moduli values, called MODULUS, was developed during this project. To assist engineers in the use of MODULUS, an expert system, called PASELS, was also developed for preprocessing and post-processing the data, focusing on local conditions.

Research has been completed, and the project report has been published as: NCHRP Report 327, "Determining Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing." The report contains users manuals for the computer programs MODULUS and PASELS. The computer programs themselves are available through McTrans at the University of Florida.

Project 10-29 FY '86 and FY '87

Anchorage Zone Reinforcement for Post-Tensioned Concrete Girders

Research Agency: University of Texas at Austin
Principal Invest.: Dr. John E. Breen
Effective Date: October 1, 1986
Completion Date: September 30, 1992
Funds: $489,223

The AASHTO *Standard Specifications for Highway Bridges* do not provide adequate guidance for designing reinforcement for tendon anchorage zones of post-tensioned concrete girders and slabs. Current designs can result in excessive cracking or congested reinforcing details. The wide variation of design practices currently in use suggests the need for research in this area.

Recent investigations at the University of Texas at Austin have developed design procedures for single tendons anchored in the webs of girders. However, additional information is needed for multiple tendons and other problems such as: influence of additional shear in support regions, bearing stresses for different types of anchorage systems, and the influence of diaphragms. Design criteria are needed for reinforcement details for inclined, sharply curved, and/or highly eccentric tendons, and for intermediate anchorages and coupling joints of tendons.

The objective of this research is to develop design procedures for end and intermediate anchorage zones for post-tensioned concrete girders and slabs. The research will include the following tasks:

Task 1—Review of relevant domestic and foreign research findings, available performance data, current domestic and foreign practice, and tendon-supplier recommendations. This information would be assembled from technical literature, unpublished experiences of engineers and tendon suppliers, insurance company records, and surveys of bridge and containment vessel owners, fabricators and designers. This review would include but not be limited to:

a. Procedures used for selecting and designing the different types of tendon anchorage systems and the factors affecting the reliability of these systems.

b. Procedures used for determining the placement and alignment of tendons, for proportioning the reinforcement surrounding the tendon anchorage, and for considering interaction effects for multiple tendons.

c. Procedures adopted for matching reinforcement requirements for anchorage zones with reinforcement requirements for shear, torsion, and continuity.

d. Procedures adopted for considering bearing effect and tendon curvature at anchorages.

e. Procedures to consider effects from factors such as highly skewed structures, diaphragms, and end blocks.

f. Procedures to determine serviceability and failure behavior.

Task 2—On the basis of the information assembled in Task 1, evaluate the available design concepts for proportioning end and intermediate anchorage zone reinforcement. Identify the limitations to existing knowledge and design concepts. Determine factors in need of detailed evaluation. Conduct preliminary analytical studies to evaluate the relative importance of these factors and to assist in the development of a detailed research plan, including laboratory and analytical studies, needed to accomplish the project objective.

Task 3—Within 12 months of contract initiation, submit the proposed research plan for NCHRP approval in the form of an interim report.

Task 4A—After NCHRP review, modification, and approval of the detailed research plan developed under Task 2, conduct the laboratory tests and analytical studies.

Task 4B—The analytical approaches will be extended to include some nonlinear finite element modeling which will track the possible cracking of anchorage zones and study the effect of nonlinear compression constitutive relations. The applications to be studied include: multiple anchorages along slab edges; end anchors; end anchorages in wider diaphragm type applications; and intermediate anchorages.

Task 5A—On the basis of the available information, experimental data, and analytical results, develop procedures to determine end and intermediate anchorage zone reinforcement for post-tensioned concrete girders.

Task 5B—The criteria will be extended to develop analysis and proportioning criteria for: anchorages in diaphragms and for the effects of local concentrated loads and reactions; distribution of load transfer reinforcement in front of and

behind intermediate anchorages; and for intermediate anchorage zones such as slab, flange, and corner blisters including out-of-plane deviation effects.

Task 6—Prepare specification provisions to reflect accomplishment of the objectives in a format suitable for consideration for adoption by AASHTO. The recommended specifications shall be accompanied by a detailed commentary and design examples intended to facilitate their understanding and use.

Task 7—Identify areas in need of further investigation. Recommend priorities and estimate time and costs for needed research.

Task 8—Prepare a final report containing the research findings and proposed design procedures.

The research has validated the effectiveness of the use of strut-and-tie models. On the basis of that validation, Tasks 4B and 5B were added to the research plan in mid-1988 to extend the applicability of the criteria developed in the project.

Research on the project was completed in 1992. The project report will be published as NCHRP Report 356 in early 1994. AASHTO is balloting on adoption of the specification recommendations.

Project 10-30(3) FY '86

Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables

Research Agency:	University of Manchester
Principal Invest.:	Dr. D. Gareth John and Prof. F. M. Burdekin
Effective Date:	July 1, 1987
Completion Date:	April 30, 1991
Funds:	$400,000

There is growing concern about corrosion, deterioration, and structural integrity of steel components used in cable-stayed bridges and segmentally constructed concrete bridges when these components are placed in ducts or embedded in concrete and thereby not accessible for visual inspection and evaluation. To make informed decisions on maintenance and rehabilitation of bridge members, engineers need to know the rate at which deterioration or distress is occurring and the extent of damage that has already taken place. Various nondestructive inspection (NDI) methods that could be used to evaluate the condition of these steel components should be assessed, and one or more practical systems for on-site inspection and evaluation of steel components in bridge members should be developed for field use.

After reviewing the results of Projects 10-30(1) and 10-30(2), the University of Manchester Institute of Science and Technology's proposed plan for a Phase II was chosen by the NCHRP. Accordingly, the objective of Phase II was to experimentally evaluate the chosen methods using realistic bridge components.

Research focused on the development of an ultrasonic technique to interrogate the condition of prestressing steel in concrete. The research has thoroughly explored various options and is now complete. A prototype ultrasonic device employing "rolling transducers" was developed; however, the device, in the opinion of the NCHRP, has very limited capabilities rendering it impractical for actual field applications. Nevertheless, the research experiments are exceptionally well documented and will be a relevant source for future forays on this subject.

Research Results Digest No. 188, "Ultrasonic Nondestructive Testing for Deterioration of High-Strength Steel Components Embedded in Concrete," summarizes the research effort. The agency's complete final report was also distributed to all state DOTs and is available to others on loan or for purchase on request to the NCHRP.

Project 10-31 FY '86

Acceptance Criteria for Steel Bridge Welds

Research Agency:	Materials Research Laboratory, Inc.
Principal Invest.:	Dr. P. B. Crosley Dr. E. J. Ripling
Effective Date:	January 1, 1986
Completion Date:	December 31, 1989
Funds:	$348,350

Use of inaccurate methods of nondestructive evaluation and empirical acceptance criteria for bridge welds has resulted in unnecessary repair of welds and has permitted unsound welds to be incorporated in some bridges. Failure to apply accurate bridge weld quality acceptance criteria can significantly increase construction and maintenance costs or can lead to structural failures. Unnecessary weld repairs can generate harmful residual stresses and distortion and can often create new and more serious discontinuities.

Project 10-31 was initiated with the objective of developing needed improvements in bridge weld acceptance criteria. The research entailed collecting and evaluating existing literature and data, and performing analytical studies and laboratory tests to develop new data. During the course of the study, the technology for weld inspection and weld flaw quantification was also under development and was expected to play an important role in this research. However, the expected improvements in inspection and quantification technologies did not appear in time. Therefore, the acceptance criteria developed on the project was based on existing, knowingly inaccurate, inspection and quantification methods. The developed criteria are sufficiently flexible, however, so that they can be adjusted and improved as technology permits in the future.

The findings of the project and recommended acceptance

criteria are included in NCHRP Report 335, "Acceptance Criteria for Steel Bridge Welds."

Project 10-32A FY '87

Durability Testing of High-Strength Concrete Containing High-Range Water-Reducing Admixtures

Research Agency: Utah State University
Principal Invest.: J. Derle Thorpe
Effective Date: October, 1, 1987
Completion Date: April 30, 1993
Funds: $249,238

Interest in the use of high-range water-reducing (HRWR) admixtures, also known as superplasticizers, for concrete is increasing. These admixtures can markedly improve the workability of concrete mixtures. They also have the potential for producing very high strength, durable portland cement concrete by reducing the amount of water used while still allowing conventional placement methods.

Research indicates that these admixtures may affect entrained-air void systems. Air void spacing factors below 0.008 in. seem to correlate with expected satisfactory "freeze-thaw" resistance as predicted by laboratory tests. However, higher spacing factors often found in concrete placed using HRWR admixtures may or may not produce laboratory results predicting poor durability. Because of the poor correlation between air void characteristics of concretes containing HRWR admixtures and laboratory durability test results, a question arises concerning the relationship of air void characteristics and durability. There are also concerns about the influence of other concrete properties on durability and the ability of current freeze-thaw testing procedures to adequately measure durability in the laboratory as a predictor of field performance.

Therefore, research should be conducted to improve laboratory testing procedures for evaluating freeze-thaw durability and to better understand the parameters that influence the durability of concretes containing HRWR admixtures. The major concern is the testing of concretes with low water-cement ratios containing HRWR admixtures so that the benefits of high strength and decreased permeability can be realized.

The objectives of this research are to: (1) investigate the significance of various concrete properties, such as air-void characteristics, on the durability of high strength concretes (compressive strength greater than 4,000 psi) containing high-range water-reducing (HRWR) admixtures, and (2) compare and assess the variability of durability factors calculated from various methods of testing concretes for freezing and thawing durability. To accomplish these objectives, the following tasks shall be performed:

Task 1—Conduct a survey of state highway agency practices for performing and applying the results of laboratory freeze-thaw tests.

Task 2—Design a partial factorial testing program to compare and evaluate laboratory methods of freeze-thaw testing considering the effects of various characteristics of the concretes. The test program shall include procedures defined in ASTM C671, ASTM C666 Procedure A (2 hr/ cycle), and ASTM C666 Procedure A (5 hr/cycle), and the most common procedure used by states based on Task 1. Details of the measurements and the analyses to be performed on specimens shall be included. Specimens shall be cured as prescribed by the ASTM procedures except that one set of specimens in each test group shall be tested after 2 additional weeks of air drying. The concrete mixtures shall include 3 generic types of HRWR admixtures, multiple cement factors, and a range of air void characteristics. (The recommended testing program must be submitted to the NCHRP for approval prior to conducting subsequent tasks. Two months are expected to be required for review by the NCHRP.)

Task 3—Conduct test program as approved in Task 2.

Task 4—Analyze the data and develop relationships.

Task 5—Prepare the final report including conclusions and recommendations on factors that affect the durability of concretes containing HRWR admixtures, appropriate laboratory testing procedures that produce realistic results, and acceptable air void characteristics of high-strength concrete.

The preliminary draft final report has been reviewed by the NCHRP panel. Review comments are now being considered by the agency. A revised report is anticipated.

Project 10-33 FY '86

Potential Benefits of Geosynthetics in Flexible Pavement Systems

Research Agency: Georgia Tech Research Corporation
Principal Invest.: Dr. Richard D. Barksdale
Effective Date: January 6, 1986
Completion Date: December 15, 1988
Funds: $100,000

This study was primarily concerned with the reinforcement of the aggregate base of a surfaced, flexible pavement system using geosynthetics (i.e., geotextiles and geogrids). Separation, filtration, and durability were also considered. Specific methods of reinforcement that were evaluated included: (1) placing the reinforcement within the base, (2) pretensioning a geosynthetic within the base, and (3) prerutting the aggregate base with and without reinforcement. Both large-scale laboratory tests and an analytical sensitivity study were conducted. Recommendations were also made for full-scale field studies.

Research is complete, and the principal findings have been published in NCHRP Report 315, "Potential Benefits of Geosynthetics in Flexible Pavements." Additional details on the laboratory tests and the analytical study plus plans

for full-scale field tests are available in an agency report titled, "Supplement to NCHRP 315, Potential Benefits of Geosynthetics in Flexible Pavements." The supplemental report was distributed to NCHRP sponsors only. However, others may obtain loan copies or purchase ones for the cost of reproduction (see final page of this document for ordering information).

Project 10-34 FY '86 and FY '90

Transient Protection, Grounding, and Shielding of Electronic Traffic Control Equipment

Research Agency: Georgia Tech Research Corp.
Principal Invest.: Hugh W. Denny and Peter S. Parsonson
Effective Date: March 1, 1986
Completion Date: April 30, 1992
Funds: $339,988

Electronic traffic control equipment is highly susceptible to disrupted operation and even permanent damage caused by electrical noise and transients (voltage spikes and surges) associated with connected service and signal lines. Lines providing electrical power and cables interconnecting equipment to sensors, communications systems, or peripheral hardware provide a direct path for the conduction of disruptive and damaging electrical transients from externally generated electrical noise. Lightning, switching transients, and other electromagnetic interference (EMI), including radio frequency interference (RFI), may be conducted on electrical and signal lines connected to traffic control equipment. Some disruptive noise may even originate from companion equipment located within the traffic control cabinet.

The problem of electrical transient damage to electronic control equipment may be minimized and in most cases eliminated by proper application of existing technology, i.e., currently available devices may be able to provide sufficient protection against equipment malfunction and deter damage. However, there are no widely accepted specifications or procedures for application of such devices to the control equipment cabinet, terminal blocks, and associated wiring. There is a need to develop such specifications and procedures and to make them available to operating agencies to obtain maximum benefit from the protection devices.

The objectives of this research are to: (1) review current practice and develop recommended procedures for the transient protection, grounding, shielding, and filtering of power and signal conductors, cabinets, and equipment associated with traffic control to assure the proper operation and extended life of the electronic equipment; (2) develop recommended performance specifications and test methods for protective devices; and (3) develop a user's handbook and a video-training tape. To achieve these objectives, the following tasks will be accomplished:

Task 1—Review all available research and technical literature to characterize the magnitude and waveform of transients on all input and output lines of equipment cabinets and to obtain related information for use in subsequent tasks.

Task 2—Identify and summarize current practice (performance specifications, test methods, and installation and maintenance procedures) of the traffic signal community.

Task 3—Develop preliminary draft procedures for providing transient protection of electronic traffic control equipment.

The procedures will address:

a. Ground rods and grounding networks.
b. Bonding and shielding of cabinets, equipment, wiring, and conduit.
c. Protection of cabinet power and signal circuits, including dress and respective location of all wires and harnesses.
d. Fuses and circuit breakers.
e. EMI/RFI filters.
f. Transient protection devices.
g. Test methods and procedures to verify the above.

Describe how the procedures can be applied to both new and existing installations. Also describe how they can be used to mitigate line transients from direct, near, and distant lightning strikes and from conducted and radiated EMI and RFI.

Task 4—Prepare and submit an interim report presenting the findings from Tasks 1 through 3 and also include a preliminary table of contents for the final report and user's handbook.

Task 5—Prepare final recommended procedures, performance specifications, test methods, and estimated hardware costs for transient protective devices for AC service and signal conductors, detector inputs, and communication lines (AC and DC).

Task 6—Prepare a final report and a user's handbook documenting the recommendations and specifications developed in Task 5. Include in the final report discussion of the rationale and implications of each recommendation along with applicable cautions. Describe in the user's handbook representative components, materials and assemblies, specifications, and procedures.

Task 7—Prepare a reproducible video-training tape in ½-inch VHS format in 30-minute segments keyed to the sections of the user's handbook. Prepare an instructor's guide to supplement the user's handbook and training tapes.

The final report on the initial phase of research has been published as NCHRP Report 317, "Transient Protection, Grounding, and Shielding of Electronic Traffic Control Equipment."

A second phase of the research, jointly funded by FHWA and NCHRP, includes the following tasks:

Task 1—The video tape produced under Phase I, "The Nuts and Bolts of Jolts," will be reviewed and revised in

accordance with project panel review comments, and a new version will be delivered.

Task 2—A field guidelines document will be produced, in "vest pocket" format, for use by technicians and electricians for installation, protection and maintenance of traffic control hardware.

Task 3—A training course, including workshop sessions in which the participants gain hands-on experience at a number of instruction stations will be developed.

Task 4—A study of the feasibility of certification of technicians in the areas of installation and maintenance of traffic control equipment will be performed in cooperation with the International Municipal Signal Association (IMSA) and the National Institute for Certification in Engineering Technologies (NICET). Recommendations will be developed for a certification examination based on the Task 3 training course.

Task 5—A pilot presentation of the Task 3 training course will be conducted.

Task 6—A final report that documents all work on all tasks, including an evaluation of the Task 5 pilot presentation will be prepared.

All work has been completed. The final products of Phase II of the research will not be published in the regular NCHRP report series but are available for loan or purchase. They include: (1) a video tape, "The Nuts and Bolts of Jolts," (2) "Course Notes and Handout Materials" from a Pilot Short Course, and (3) "Transient Protection Practices for Traffic Control Equipment: User's Handbook." (See last page of this document for ordering information.)

Project 10-35 FY '87

Fatigue Behavior of Welded and Mechanical Splices in Reinforcing Steel

Research Agency:	Wiss, Janney, Elstner Assoc., Inc.
Principal Invest.:	Conrad Paulson and John M. Hansen
Effective Date:	November 1, 1987
Completion Date:	April 30, 1991
Funds:	$300,000

An increasing number of bridges are being rehabilitated and widened in order to accommodate increasing traffic volumes and loads. In order to transfer reinforcing steel stresses from the newly repaired or widened concrete to the original structure, welded or mechanical splices are required during construction. The objective of this research was to assess the fatigue behavior of typical welded or mechanical reinforcing steel splices and to develop practical fatigue design guidelines for situations where the splices must be used in regions of cyclic tension stress. The research included fatigue testing of a number of generic splice types and the development of recommended specifications and prequalification procedures.

Research was completed in late 1991 and the final report was submitted in early 1992. The report includes specification recommendations, which may be considered by AASHTO in mid-1994. It is expected that the report and its recommendations will be summarized in an NCHRP Research Results Digest in early 1994.

Project 10-36 FY '88

Evaluation of Weldments Incorporating Backing Materials

Research Agency:	Fleet Technology Limited
Principal Invest.:	M. Lalit Malik
Effective Date:	May 2, 1988
Completion Date:	September 30, 1993
Funds:	$349,475

In current steel bridge fabrication the material most commonly used as a backing for groove welds consists of a continuous steel bar placed against the backside of the groove. This permits complete joint penetration groove welding from one side only. Codes require the weld metal to be thoroughly fused with the steel backing. This fabrication technique is widely accepted, particularly when access to the far side of the joint being fabricated is restricted. Typical applications where access may be restricted are in welded box girders and columns. In some cases, the backing bar is removed after the groove weld has been completed. However, this is not always possible or necessary.

Fused weld backing becomes an integral part of the structure and must be continuous, otherwise sharp, localized discontinuities will concentrate stresses and cause weld cracking. Additionally, the orientation of the backing relative to the direction of the applied stress is critically important. While careful adherence to existing codes regarding design, assembly, welding procedure, workmanship, and testing should lead to acceptable performance, the essentials of good practice are not widely understood. Guidance is required for bridge designers, fabricators, and inspectors on the proper detailing and fabrication procedures for complete joint penetration groove welds incorporating fused steel backing bars.

The geometry of restricted access, complete joint penetration groove welds precludes the use of through-thickness nondestructive evaluation procedures other than ultrasonic testing. However, the presence of the fused steel backing compromises the accuracy of such tests. Additionally, precise measurements of the effective weld throat are often impossible. These problems may be alleviated by the use of other backing materials and designs. However, little information is available for the designer, fabricator, and inspector on the performance of such alternative backing materials in steel bridge applications. Research is needed to identify suitable alternative backing materials and designs appropriate for bridge applications.

The objective of this research is to develop a better understanding of the performance characteristics of fused steel

bars and alternative weld backing materials, and to determine their potential benefits and limitations in bridge design and fabrication.

The research will include the following tasks:

Task 1—Review relevant current domestic and foreign codes of practice, performance data, and research findings related to typical bridge framing connections using fused steel backing bars. This information shall be assembled from both technical literature and unpublished experience of designers, fabricators, inspectors, and owners of steel bridges.

Task 2—From the Task 1 findings, develop a user's guide for designers, fabricators, and inspectors providing specific recommendations for the use of fused steel backing bars. The guide should identify critical details and provide appropriate cautions and limitations.

Task 3—Review relevant current domestic and foreign codes of practice, performance data, and research findings related to the use of nonmetallic, nonfused backing materials. Materials such as carbon, which may adversely interact with molten metal or the welding arc, should not be considered.

Task 4—Select a limited number of nonmetallic, nonfused backing materials that may be appropriate for steel bridge applications. Determine if the details of welded joints shown in Chapter 2 of the AWS D1.1 Structural Welding Code—Steel, are appropriate for use with these selected backing materials. (The selected backing materials will be used in laboratory studies to be conducted in Tasks 6 through 9.)

Task 5—Present the findings of the first four tasks in an interim report to be submitted not later than 9 months after initiation of this study. The interim report shall present a detailed research plan for the remainder of the study. NCHRP approval of the detailed research plan will be required before commencing Task 6.

Task 6—Conduct laboratory tests on weldments made with the selected nonmetallic, nonfused backing materials. Tests should include metal chemistry, metallurgical studies, and mechanical tests to ensure that there are no adverse effects on the weld or base material.

Task 7—Fabricate representative T- and corner-complete joint penetration groove welds using fused metal backing bars and the selected nonfused backing materials. During the fabrication process, methods shall be used to induce acceptable and rejectable discontinuities defined by Paragraph 9.25 in AWS D1.1. Perform and report on ultrasonic indications as required by Chapters 6 and 9 of AWS D1.1.

Task 8—Verify and characterize the existence of representative ultrasonic test indications in the welds produced in Task 7.

Task 9—Conduct performance tests on weldments fabricated with the selected nonfused backing materials and on T-joints with fused backings loaded in the transverse direction. The purpose of these tests will be to identify the advantages and disadvantages of their use in steel bridge applications.

Task 10—Prepare a final report documenting all research. The final report shall include recommendations for areas in need of further investigation.

The revised user's guide was submitted in late 1993. It contains recommendations on the use of nonfused materials as well as fused backing materials with applied cyclic stresses transverse to the axis of the weldment. The draft final report documenting all of the project research is expected in January 1994.

Project 10-37 FY '91

Performance of Epoxy-Coated Reinforcing Steel in Highway Bridges

Research Agency:	Kenneth C. Clear, Inc./Florida Atlanta University
Principal Invest.:	Mr. Kenneth C. Clear and Dr. William H. Hartt
Effective Date:	May 1, 1991
Completion Date:	January 31, 1994
Funds:	$350,000

The highway industry has made extensive use of epoxy-coated reinforcing steel bars in bridges during the last 15 years. Many states now specify epoxy-coated bars as the preferred protective system to reduce corrosion-induced deterioration in concrete bridge decks. As an extension of the concept, epoxy-coated bars have also been used in concrete substructure elements; however, there are differences in deck and substructure applications, especially, in respect to the size of bars and the amount of fabrication (i.e., the amount of bending in the bar after the epoxy coating has been applied).

Recently, extensive premature corrosion of epoxy-coated reinforcing steel bars has been observed in various substructure members of bridges built within the last 6 to 9 years in the Florida Keys. The corrosion was initially observed in areas that contained bent reinforcing steel bars, but later it was also found on straight bars. These deteriorating members are in the "splash zone" and, thus, are subjected to salt spray and cycles of wetting and drying. High air- and water-temperatures also contribute to an adverse environment. Other isolated instances of unsatisfactory performance of epoxy-coated reinforcement have been noted (e.g., in a test pile in Oregon and a bridge deck in New York).

The reasons for corrosion of epoxy-coated steel in highway bridges are not clear. Coated defects, improper coating application, poor handling practices, prolonged storage on-site, and exposure of reinforced concrete elements to highly corrosive environments are possible factors affecting performance.

The objectives of the research are to determine the reasons for unsatisfactory corrosion performance of epoxy-coated reinforcing steel, where it has occurred in highway bridges, and to make recommendations for improvements to current practice and specifications. Accomplishment of the objectives will require, as a minimum, the following tasks:

Task 1. Evaluate and comment on existing practice and specifications, existing information on the performance of epoxy-coated reinforcement in bridges and other structures, and completed and ongoing research.

Task 2. Identify and, if necessary, develop techniques for evaluation of epoxy-coated reinforcing steel intended for use in concrete bridge structures. This will include (1) the evaluation of coated reinforcing steel prior to concrete placement, (2) the inspection of reinforcing steel in existing structures, and (3) the examination in the laboratory of samples removed from structures or construction sites.

Task 3. Develop a work plan for Task 4, which provides further detailing of the methodology and testing techniques to be used, the structures to be evaluated, details of the sampling plan, and proposed schedules. The purpose of the testing program will be to identify factors that affect the good and bad performance of epoxy-coated reinforcement.

An interim report, which includes the findings of Tasks 1 and 2 and the work plan developed in Task 3, shall be submitted to the NCHRP within 12 months of contract initiation and must be approved prior to conducting subsequent tasks.

Task 4. Conduct the approved work plan. The field surveys shall consist of two different types of investigations. The first is a pre-placement evaluation to inspect, sample, and test epoxy-coated reinforcing steel immediately prior to placement of the concrete. The second is an in-service evaluation to inspect and sample epoxy-coated reinforcing steel in existing structures. After field comparisons of good and bad performance and laboratory examinations of samples have been completed, assess the results of all investigations to determine which factors affect the performance of epoxy-coated reinforcing steel and quantify the relative importance of each.

Task 5. Prepare a final report containing the research findings and specific recommendations for improvements in current specifications and practice.

Tasks 1, 2, and 3 are complete, and the agency's interim report on Tasks 1 and 2 is available for loan on request. Under Task 4, field site evaluations and experimental laboratory testing are proceeding. More emphasis has been placed on laboratory experiments for the performance of epoxy-coated reinforcing steel and less, than originally planned, on field evaluations. This shift in emphasis was prompted by previous agency work for other clients where field samples indicated a need to better understand the performance of epoxy as a coating.

The field evaluations are to help assess the condition of epoxy-coated reinforcing steel as handled and placed in actual construction projects. An AC resistance test will be used to make an assessment of the quality of the coating. The experimental laboratory tests will be examining various techniques for evaluating the performance of epoxy-coated reinforcing steel bars and correlating the results with laboratory specimens subjected to various accelerated environmental conditions. The purpose is to determine what type of testing seems to predict better performing coated bars.

Project 10-38 FY '93

Fatigue-Resistant Design of Cantilevered Signal, Sign, and Light Supports

Research Agency: Lehigh University
Principal Invest.: Mark Kaczinski
Effective Date: January 1, 1993
Completion Date: June 30, 1995
Funds: $300,000

The AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* have been the basis for the design of signal-, sign-, and light-support structures since its adoption in 1968. Most structures designed in accordance with these specifications have performed satisfactorily.

Vibration and fatigue are of concern in all wind-loaded structures, but cantilever structures are especially vulnerable to failure from wind-induced fatigue damage. The present specifications include provisions for vibration and fatigue design. However, there is concern about the accuracy and clarity of the provisions, and the commentary does not contain adequate guidance for application of the provisions. Several recent fatigue failures underscore the need for improved specifications and design procedures.

Research is therefore needed to develop improved specifications that will result in fatigue-resistant designs of cantilevered signal-, sign-, and light-support structures. The objective of this research is to develop rational design procedures and recommended specifications that consider wind-induced cyclic stresses in cantilevered signal-, sign-, and light-support structures.

The project will include the following tasks:

Task 1. Collect and review relevant domestic and foreign literature, research findings, performance data (including reports of cracking in or failure of structural supports), and current design practices for cantilevered signal-, sign-, and light-support structures. A number of states and organizations have ongoing projects related to this topic, and coordination with these agencies is recommended.

Task 2. Collect and review relevant literature and data on the analysis and design of other wind-loaded structures.

Task 3. A number of factors, such as aeroelastic effects, structural configuration, support conditions, material properties, or site conditions, may affect the performance of signal-, sign-, and light-support structures. Identify the pertinent factors and prioritize those important to the development of improved design procedures and specifications.

Task 4. Develop a detailed research plan to quantify the wind-induced cyclic stress effects in terms of the critical parameters identified in Task 3 including methods for integ-

rating the research results into design procedures and recommended specifications.

Task 5. Submit an interim report presenting the results of Tasks 1–4 within 9 months of the commencement of the project. The interim report should include the Task 4 research plan and an associated budget. NCHRP approval of the interim report and the detailed research plan will be required before research on the remaining tasks may commence.

Task 6. Perform analytical studies, experimental investigations, or both, in accordance with the approved research plan.

Task 7. Prepare the recommended specification provisions, commentary, and design procedures, in a format suitable for inclusion in the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals.*

Task 8. Prepare and submit a final report containing the research findings, recommended specifications, commentary, and design procedures, as well as recommendations for further research.

An interim report that documents Tasks 1 through 4 was submitted in late 1993 and is currently under review.

Project 10-39 FY '93

Construction Testing and Inspection Levels

Research Agency:	Bergstralh-Shaw-Newman, Inc
Principal Invest.:	Robert B. Newman, Verdi Adam and Sanford P. LaHue
Effective Date:	January 6, 1993
Completion Date:	December 5, 1993
Funds:	$140,000

Among a variety of responsibilities, transportation agencies must provide the general public with the best highway facilities possible, given available resources. Traditionally, agencies have engaged in extensive testing and inspection efforts to assure construction quality and, thereby, the satisfactory performance of the facility. Although serving the public well, such efforts consume an appreciable amount of resources. Throughout the country, limitations on staffing levels, combined with expanding construction programs, are forcing agencies to reexamine current levels of testing and inspection and the manner in which these quality assurance efforts are accomplished.

Although there have been successes, previous research on this subject often has been difficult to interpret and apply and has resulted only in incremental benefits in optimizing construction testing and inspection programs. Innovative techniques and methods must be investigated to assure continued quality in management of construction testing and inspection. Past and current research will be useful, but it is imperative that research now explore new and creative methods and produce results readily implementable by transportation agencies and the highway construction industry.

The objective of this research is to develop administrative and technical guidelines for transportation agencies to use in establishing methods and optimal levels of inspection and testing for construction programs and projects. Innovation is critical for the successful accomplishment of the research objective. As a minimum, the following tasks are expected to be required:

Task 1. Conduct a comprehensive review of pertinent literature and current research from the highway industry and other related construction industries from both domestic and foreign sources.

Task 2. Survey the construction industry to determine the methods, including the type and frequency of inspection and testing, for all commonly controlled parameters that are relevant to highway construction—distinguish between method (prescription) and end-result approaches. In particular, seek to determine what quantifiable basis, if any, was used to establish current levels of inspection and testing for items critical to the quality and performance of the contracted facility while considering the importance of safety and economics.

Task 3. Prepare a detailed work plan for the development of the administrative and technical guidelines. These guidelines must focus on methods having the greatest impact and may address such issues as: staffing requirement, types of specifications, and the methods and techniques for assuring quality. The work plan will be submitted to the NCHRP for review and approval prior to the conduct of subsequent tasks. (In addition, the contractor must be prepared to make an oral presentation to the NCHRP. The NCHRP reserves the right to terminate the project after Task 3.)

Task 4. Implement the Task 3 work plan and develop the guidelines. Recommend demonstrations of selected portions of the guidelines with cooperating state highway agencies. (For estimating the size and nature of the recommended demonstrations, assume a budget of $100,000 for 18 months—not included in total funds and contract time shown below.)

Task 5. Prepare a final report including the guidelines and a plan for the recommended demonstrations.

Task 6. Conduct the demonstrations and modify the guidelines if needed. This task is optional, to be determined by the NCHRP, and will not be included in the initial contract for this project.

At the present time, the NCHRP has only contracted for Tasks 1 through 3. The remaining tasks will be accomplished if Tasks 1 through 3 demonstrate promise.

Project 10-40 FY '93

Plasma Arc Cutting of Bridge Steels

Research Agency:	Edison Welding Institute
Principal Invest.:	Ian D. Harris
Effective Date:	January 18, 1993
Completion Date:	April 17, 1995
Funds:	$268,688

Plasma arc cutting of steel plates can offer substantial advantages in terms of speed and economy when compared with oxy-fuel cutting. However, existing standards do not contain sufficient guidance for engineers, fabricators, and inspectors on plasma arc cutting or on the need for edge treatment. Therefore, there is a reluctance to use plasma arc cutting during fabrication of steel bridges.

Some of the concerns regarding the use of plasma arc cutting techniques and procedures are: (1) the effects of process variables such as speed, current and voltage, gases, pre- and postheat, and water quenching; (2) the effects of material variables such as steel grade and surface condition; (3) the characteristics of the free edge including hardness, toughness, fatigue resistance, edge profile, and paint adhesion; (4) the characteristics of edges affected by welding including porosity, and heat-affected zone (HAZ) and fusion boundary properties; and (5) the need for or extent of edge treatment.

Research is needed to assess the characteristics and performance of plasma arc cut edges and to develop specifications and guidelines that will eliminate barriers to the use of this process in steel bridge fabrication. The objective of this research is to develop a user's guide and recommendation specifications for plasma arc cutting of bridge steels. Recommendations shall be based on test results of representative grades of AASHTO M270 (ASTM A709) steels in the thickness range of 3/8″ to 3/4″. The user's guide and recommended specifications shall address the performance of both free edges and edges affected by welding.

The research will include at least the following tasks:

Task 1. Review relevant current domestic and foreign practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experiences of engineers, fabricators, and bridge owners, as well as plasma arc and flame cutting equipment manufacturers and suppliers.

Task 2. Evaluate and summarize the information generated in Task 1 in order to determine current practice and the state of knowledge. Identify all conditions and parameters that may affect the performance of free edges and edges affected by welding. Identify and rank those areas where research is required to assess existing plasma arc cutting procedures and develop rational specifications.

Task 3. Propose preliminary test procedures and criteria for evaluating the acceptability of plasma arc cut edges. Develop a detailed test plan based specifically on the available funding for this project.

Task 4. From the Task 2 findings, develop a draft guide for designers, fabricators, and inspectors providing specific recommendations for the use of plasma arc cutting. The guide should provide appropriate precautions and limitations and also address repair of defects.

Task 5. Prepare and submit an interim report summarizing the findings from Tasks 1 through 4. The interim report shall be submitted not later than 6 months after the start of the project. NCHRP approval of the interim report and the detailed test plan is required before commencing with Task 6.

Task 6. Conduct laboratory tests in accordance with the approved test plan from Task 5.

Task 7. Analyze the results of the tests performed in Task 6 and summarize the findings. On the basis of these findings, develop recommended specifications and commentary for plasma arc cutting in a format suitable for adoption by AASHTO and AWS. Revise the draft user's guide to reflect the test findings.

Task 8. Prepare and submit a final report documenting all research findings and provide recommendations for further research.

Research on Tasks 1 through 4 has been completed and the interim report, prepared in Task 5, has been reviewed and approved. Work on Task 6 is proceeding on schedule.

Project 10-41 FY '94

Evaluation of Unbonded Portland Cement Concrete Overlays

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	(21 Months)
Completion Date:	
Funds:	$200,000

Portland cement concrete pavements constitute a large portion of those pavements that are designed to carry a high volume of heavy traffic. Many of these pavements are now approaching the end of their design life, and others have reached their terminal serviceability level. The need to develop appropriate techniques for rehabilitating those pavements is becoming increasingly important. One such technique that deserves further evaluation involves resurfacing the old pavement with a portland cement concrete overlay, which is separated from the existing pavement with an interlayer (bond breaker). This type of resurfacing—commonly referred to as unbonded overlay—improves the structural capacity of the old pavement and enhances rideability by providing a new surface.

Guidelines that identify recommended design and construction features on unbonded concrete overlays would help highway authorities to select suitable and reliable details for the rehabilitation of portland cement concrete pavements.

The objectives of this research are to (1) evaluate the performance of existing techniques for rehabilitating portland cement concrete pavements with unbonded concrete overlays, (2) assess the expected long-term performance of these techniques, and (3) recommend guidelines for the use of unbonded concrete overlays.

To accomplish these objectives, the following two research phases will be conducted:

Phase I: (1) Identify the site conditions and design parameters necessary to characterize the performance of unbonded

concrete overlays. Examples of site conditions include traffic loading, climate, and roadbed soil type. Examples of design parameters include type of interlayer (e.g., bituminous, granular, permeable bituminous treated), type and condition of the existing pavement, overlay type (e.g., jointed plain, jointed reinforced, continuously reinforced), and other features (e.g., shoulders, drainage provisions, cross section details). Consideration shall be given to unbonded overlays that are wider than the underlying pavement. (2) Review information in both foreign and domestic databases and literature and survey highway agencies to obtain information on the practices and performance of unbonded concrete overlays. Supplement this information with field visits and field observations, as appropriate. Compile a summary of current practices, which shall be submitted with the interim report (Task 4) for possible publication by NCHRP. (3) Develop a detailed work plan for Phase II that encompasses analytical and/or experimental investigations for estimating the long-term performance of unbonded concrete overlays, based specifically on the funds available for this research project. The proposed plan must consider those factors that influence overlay performance and reflect the proposer's current thinking on how these factors will be identified and evaluated. (4) Prepare an interim report that (a) documents the research performed in Tasks 1 through 3 and (b) provides the updated work plan for the Phase II portion of the project, describing rationale, methods, schedule, budget, and other required details. Following review of the interim report by the project panel, the research team will be required to make a presentation to the project panel.

Phase II: (5) Execute the work plan approved in Task 4. Proposals are expected to present the proposers' current thinking in sufficient detail to demonstrate their understanding of the problem and the soundness of their approach to developing estimates of the long-term performance of unbonded overlays. (6) Develop guidelines for the design and construction of unbonded concrete overlays for conditions encountered on U.S. highways. The guidelines should consider the design parameters and site conditions identified in Task 1, as well as the anticipated maintenance and rehabilitation needs of the overlay. Use case studies to demonstrate the validity of these guidelines. (7) Submit a final report that documents the entire research effort. The report shall include practical recommendations for the design and construction of unbonded concrete overlays, and an implementation plan for moving the results of this research into practice.

Project 10-42 FY '94

Constructibility Review Process for Transportation Facilities

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (27 Months)
Completion Date:
Funds: $250,000

Transportation agencies recognize the need for contract documents that will ensure rational bids and minimize problems during construction of facilities. A significant aspect of developing high-quality contract documents is to incorporate a review process in the planning and design phases to assess project constructibility. This process must include input from all professionals involved in the planning, design, construction, operation, and maintenance of transportation facilities. Constructibility reviews have the potential to minimize the number and magnitude of changes, disputes, cost overruns, and delays during construction.

In addition to input from experienced transportation professionals, a variety of analytical tools are available to facilitate and enhance the constructibility review process. Examples of existing tools are spreadsheets, knowledge-based expert systems, computer-aided design and drafting (CADD) systems, geographic information systems (GIS), various databases, computer simulation systems, and physical and computer-generated models.

A successful constructibility review process for a transportation agency must follow an established methodology similar to value engineering. The process must be flexible enough to apply to all types of projects handled by the agency. Furthermore, the process must address the critical issues impacting today's transportation construction projects, such as, ease of construction, environmental factors, construction phasing and scheduling, project safety, and accommodation of future maintenance and operations. To obtain maximum benefit from a constructibility review, it must be initiated early in the planning phase of the project and continue through design and construction.

Research is needed to define an appropriate constructibility review process for transportation facilities. A methodology must be developed and the proper use of professionals and analytical tools determined. Research results will enable transportation agencies to assess the applicability of construction reviews and provide guidance for implementation.

The objective of this research is to develop a methodology for a constructibility review process for application by transportation agencies. The research will include identifying concepts, evaluating the application of existing analytical tools, and providing implementation procedures for tailoring this methodology to individual transportation agencies. Accomplishment of this objective will require at least the following tasks:

(1) *State of the Art*—Review existing literature and constructibility review practices in transportation agencies and in other construction fields with relevance to construction of transportation facilities.

(2) *Critical Issues*—Identify and analyze critical constructibility issues common to most transportation agencies. Document procedures used to identify these issues.

(3) *Preliminary Constructibility Review Process*—Identify and describe the key steps of a constructibility review process for transportation agencies. Include a detailed outline

of the proposed methodology with appropriate flow diagrams.

(4) *Interim Report*—Document Tasks 1 through 3 and include an updated work plan for the remaining tasks.

(5) *Review Tools*—Identify and evaluate existing analytical tools that can be used to facilitate the constructibility review process, and discuss their application. (Computer software should not be developed as part of this project.)

(6) *Review Process*—Develop a constructibility review process for use by transportation agencies. The process shall be designed considering the differing cultural and organizational structures of agencies, the level of complexity of the projects being examined, and the use of consultants.

(7) *Implementation Plan*—Provide an implementation plan for applying the constructibility review process in transportation agencies. Identify the effort and resources required to implement the process.

(8) *Final Report*—Prepare a final report that includes sections on needs for future research and new analytical tools to improve constructibility reviews in transportation agencies. The Task 6 workbook will be an appended, standalone document.

Project 10-43 FY '94

Movable Bridge Inspection, Evaluation, and Maintenance

Research Agency: Contract Pending
Principal Invest.:
Effective Date: 27 months
Completion Date:
Funds: $250,000

Some guidance is available on inspection, evaluation, and maintenance of movable bridges; however, recognizing the complexity and specialized nature of such bridges, it is timely and appropriate to update, augment, and consolidate available information. Research is needed to determine and document the best approach for inspection, evaluation, and maintenance of these bridges. Thus, a thorough review of current technology and recently completed and ongoing research is needed to produce state-of-the art guidance on assessment and condition reporting of movable bridge features (e.g., mechanical and electrical systems).

The objective of this research is to develop a recommended manual, with commentary, for the inspection, evaluation, and maintenance of movable bridges. The manual will be in a form suitable for consideration for adoption by AASHTO. To present the material more effectively, it may be divided into several manuals.

In developing the manual, consideration will be given to current codes and practice, as well as to recently completed and ongoing research. The manual should be prepared in a flexible format to allow for future revisions and will include appropriate report forms. The manual should provide guidance on all elements of movable bridges; however, to provide consistency in inspection, evaluation, and maintenance practice for the general bridge population, and to avoid duplication of material that exists for fixed bridges, inclusion of concepts appropriate for both movable and fixed bridges may be done by way of reference to existing documents. Thus, the research will focus on aspects of movable bridges that are different from fixed bridges (e.g., mechanical and electrical systems, operations, and safety). The manual will also include consideration of evaluation procedures that are applicable to bridge management systems.

It is anticipated that the research will include at least the following tasks:

Task 1. Review domestic and foreign practice and research findings, assembled from the technical literature. Solicit and review the unpublished experiences of bridge owners, maintenance personnel, manufacturers, designers, consultants, and others.

Task 2. Evaluate the information reviewed in Task 1 to determine the most up-to-date, cost-effective, and functional procedures that can be incorporated into the recommended manual.

Task 3. Prepare a detailed outline for the manual based on the findings of Tasks 1 and 2. As a minimum, the outline will include chapter and topical headings along with a description of the intent of each topic.

Task 4. Submit an interim report detailing the results of Tasks 1 through 3, including a proposed presentation format for the manual and commentary. NCHRP approval will be required before proceeding with the remaining tasks.

Task 5. Submit a complete draft manual and commentary prepared in an easy-to-revise format. Following project panel review of the manual, meet with the panel to discuss the manual and the remaining research. The contractor will formally address written panel comments regarding the manual, as well as any issues raised at the panel meeting.

Task 6. Identify and prioritize areas in the manual that may require future research to provide additional modification or improvement beyond what will be developed for this project.

Task 7. Submit a final report describing the entire research effort. Include, as an appendix, the recommended manual with commentary in a format suitable for consideration by the AASHTO Highway Subcommittee on Bridges and Structures.

AREA 11: LAW

(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)

AREA 12: BRIDGES

Project 12-15(5) FY '82

Fatigue Behavior of Variable Loaded Bridge Details Near the Fatigue Limit

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher

Effective Date: September 1, 1983
Completion Date: December 31, 1990
Funds: $399,999

The objective of this study was to extend the findings of NCHRP Project 12-15(4) (see NCHRP Report 267) by providing additional information on fatigue crack growth behavior of steel bridge members under randomly applied, variable-amplitude loadings in the fatigue limit, extreme life region. Fatigue tests were carried out on a series of full-depth plate girders in order to augment available information on the effects of infrequently exceeding the constant amplitude fatigue limit (CAFL) during the service life of steel bridges. AASHTO Category E′ web attachments and cover-plated flange details and Category C transverse stiffeners and diaphragm connection plates were tested during the program.

The variable amplitude test results were found to supplement and verify the preliminary observations reported in Report 267. They demonstrated that low levels of exceedance of the CAFL will result in fatigue cracking even when the root-mean-cube effective stress range is below the CAFL.

The final report has been published as NCHRP Report 354.

In addition to the test program directed at the primary objective, a small portion of the total effort was expended on a reassessment of the fatigue specifications in the AASHTO *Standard Specifications for Highway Bridges.* Minor revisions to the fatigue design provisions were recommended to, and adopted by, the AASHTO Subcommittee on Bridges and Structures. The evaluation and recommended specifications were published in: NCHRP Report 286, "Evaluation of Fatigue Test Data and Design Criteria on Welded Details."

Project 12-23 FY '89

Recommended Revisions to the AASHTO *Manual for Maintenance Inspection of Bridges*

Research Agency: A. G. Lichtenstein & Associates, Inc.
Principal Invest.: Dr. Abba G. Lichtenstein
Effective Date: January 3, 1989
Completion Date: August 3, 1992
Funds: $233,800

The objective of this project was to perform a complete revision and updating for the AASHTO *Manual for Maintenance Inspection of Bridges.* The existing manual was initially published by AASHTO in 1970, and since that time only minor changes and additions were made to it. At the request of AASHTO, this project was initiated in order to incorporate current practices in bridge design, construction, inspection, and analytical and physical methods for load capacity evaluation and rating.

The project was completed in mid-1992 and a new manual was submitted for consideration by AASHTO. The new manual, titled *Manual for Condition Evaluation of Bridges,* was approved for publication in late 1992 by AASHTO. It is expected that the new manual will be available from AASHTO in late 1993.

Project 12-26(2) FY '85, FY '89, and FY '92

Distribution of Wheel Loads on Highway Bridges

Research Agency:	Imbsen & Associates, Inc.		
Principal Invest.:	Roy A. Imbsen and Toorak Zokaie		
Effective Date:	4/15/85	8/22/88	9/28/92
Completion Date:	12/15/87	10/31/90	12/31/93
Funds:	$300,000	$200,000	$100,000

The objective of this research was to develop comprehensive specification provisions for distribution of wheel loads in highway bridges.

Research under NCHRP Project 12-26 considered numerous variables affecting the distribution of wheel loads. The recommended provisions apply to both the Service Load and the Strength Design Methods as well as to structural evaluation of existing bridges.

Load distribution criteria developed in this study include: (1) simplified methods of analysis including code formulas and (2) analytical models that are more comprehensive and exact and are intended for computer-based application.

The first phase of the project focused on steel and concrete beam-and-slab bridges and multi-cell concrete box girder bridges. The formulas that were developed in Phase 1 produced accurate and reliable results for moment and shear wheel load distributions. Correction factors for skew and continuity were also developed and presented in the format of an AASHTO specification.

The second phase of the project concentrated on concrete slab bridges, precast concrete multigirder bridges, and spread box beam bridges. The results of both the first and second phases of the project were combined into one comprehensive report and recommended specification.

The work completed on Phases I and II was summarized in NCHRP Research Results Digest 187 "Distribution of Wheel Loads on Highway Bridges." In addition, AASHTO considered the specification recommendations resulting from the project and balloted to adopt them as a Guide Specification in late 1992.

Phase III of the project is intended to develop a PC-based wheel load distribution software program based on grid analysis methods. The draft final report and software, submitted in mid-1993, are under review.

Project 12-27 FY '84

Welded Repair of Cracks in Steel Bridge Members

Research Agency: The Welding Institute
Principal Invest.: Mr. E. N. Gregory

Effective Date: October 15, 1984
Completion Date: February 28, 1989
Funds: $374,575

The objective of this research was to identify and evaluate welding methods for repair of cracked steel bridge members to restore their load carrying capacity and fatigue life. The research included a synthesis of existing information on welding repair procedures including an identification of the problems and solutions for repair welding of members while under traffic loading. Laboratory and field tests were performed to evaluate the proposed guidelines for welded repair of cracked steel members, and a manual of recommended practice was developed.

Research has been completed and the final report published as NCHRP Report 321, "Welded Repair of Cracks in Steel Bridge Members." The report is presented in the form of a manual of recommended practice for repair welding and includes criteria for welder qualification and specific repair procedures depending on the type and location of cracks.

Project 12-28(1) FY '85

Load Capacity Evaluation of Existing Bridges

Research Agency: Case Western Reserve University
Principal Invest.: Dr. Fred Moses
Effective Date: September 1, 1985
Completion Date: August 31, 1989
Funds: $302,000

The primary objective of this research was to develop evaluation procedures for steel bridges of different types and for prestressed concrete girder bridges based on the load and resistance factor design (LRFD) methodology. These procedures were then combined with those developed in NCHRP Project 10-15 for reinforced concrete bridges in order to create comprehensive evaluation guidelines for all typical bridge types. The guidelines were prepared in a format suitable for incorporation into the AASHTO *Manual for Maintenance Inspection of Bridges.*

The first phase of research (development of evaluation procedures for steel girder and prestressed girder bridges) was completed in 1987. The results from this phase of work were published as NCHRP Report 301, "Load Capacity Evaluation of Existing Bridges."

The second phase of research included the combination of the Project 10-15 and 12-28(1) guidelines, and the development of training materials and example problems demonstrating the use of the new guidelines. The combined guidelines were published in 1989 as AASHTO *Guide Specification for Strength Evaluation of Existing Steel and Concrete Bridges.*

Project 12-28(2) FY '85 and FY '87

Bridge Management Systems

Research Agency: ARE Inc.
Principal Invest.: Dr. W. Ronald Hudson
Effective Date: June 24, 1985 November 2, 1987
Completion Date: June 23, 1987 April 30, 1990
Funds: $225,000 $270,000

The objective of this research was to develop a model form of effective bridge management at the network level.

The first phase of research resulted in the conceptual development of the modular elements required for a model bridge management system (BMS). The elements identified for inclusion in the model BMS are: the BMS data base module; the network level maintenance, rehabilitation, and replacement selection module; a maintenance module that will assign maintenance programs in a rational and continuing way within the system; the historical data analysis module; a project level interface module; and the reporting module. The final report from the first phase research has been published as NCHRP Report 300, "Bridge Management Systems."

A second phase of research was initiated with the objectives of finalizing the engineering concepts necessary for bridge management systems and to produce a PC-based computer software package. The resulting software package was tested by several state and local transportation agencies. Based on this testing, it was determined that the software lacked many necessary features for basic operation and had a large number of errors in the software code. Therefore, another project was initiated to further develop and finalize a software package that met minimum anticipated federal requirements for bridge management systems but which was also easy to operate and maintain. See the summary for NCHRP Project 12-28(2)A for a detailed description of this follow-on project.

Project 12-28(2)A FY '92

Bridge Management Systems Software

Research Agency: National Engineering Technology Corp.
Principal Invest.: Stephen Lipkus
Effective Date: January 10, 1992
Completion Date: Sept. 30, 1994
Funds: $525,000

NCHRP Project 12-28(2), Bridge Management Systems, was initiated in 1985 with the objective of developing a model form of effective bridge management at the network level. The first phase of the project resulted in the conceptual development of the modular elements necessary for a model bridge management system, which is documented in NCHRP Report 300, "Bridge Management Systems." A second phase of work further developed some engineering concepts neces-

sary for operation of such a system and initiated program development. An IBM PC-based computer program was produced using the FoxBase database programming language.

Four state transportation departments tested and evaluated the software. Based on the results of this testing, a number of major deficiencies were identified in the system. In addition, several optimization and analysis concepts and strategies that were not incorporated in the initial system design are needed to ensure compliance with anticipated future federal requirements.

The objective of NCHRP Project 12-28(2)A is to develop, validate, and document a fully operational microcomputer-based bridge management system software package that can be readily used by transportation agencies. The system will be based on the conceptual design noted in NCHRP Report 300, modified as necessary to incorporate other elements and strategies as noted below.

The completed bridge management software program will meet the following requirements, and accommodate and incorporate elements as noted: IBM PC or compatible hardware platform; developed using commercially available database and/or high-level languages; modular design and execution; conventional engineering procedures such as deterministic deterioration models, incremental cost-benefit analysis, and life cycle cost profiles; incorporation of level-of-service goals; network level decision-making, with a capability to link to project level decision-making in the future; reasonable predictions of deterioration rates of structural elements; optimization of the selection of projects and inclusion of alternatives based on maintenance, rehabilitation, and replacement; optimization of maintenance options; user cost considerations in the optimization strategies; optimization on the complete bridge network or any subset of it and with unconstrained and constrained budgets; ability to forecast annual needs over a predefined planning horizon, both for the complete network and any subset of it; direct data upload capabilities from state NBI databases, supplemented by other easily collectible data as required; easy data entry and editing; output capabilities must include network and network subset data files and flexible report formats that can be written to disk, screen, and hard copy; levels of security and access rights; and, operational as a single-user system with capabilities to be expanded to a multi-user system in the future.

The following deliverables will be provided: complete system and module design documentation including flowcharts, algorithms, required inputs, system communications, and module outputs; software source code; compiled and executable software package; software package installation and NBI data upload specifications or routines; and system documentation. The system documentation will include the system design documentation, user's manual, programmers manual, and a system validation report.

The project will include the following tasks:

Task 1. Review all appropriate materials necessary for the development of a final system design. Review and evaluate various alternatives and strategies for optimization, economic analysis, deterioration, and user costs.

Task 2. Develop the final system design, design documentation, and a system validation plan.

Task 3. Submit an interim report within 4 months of project initiation which summarizes the material in Task 1 and provides rationale for the alternatives selected. The interim report must provide the completed system design documentation and validation plan. NCHRP approval of the design documentation will be required before proceeding with Tasks 4 through 6.

Task 4. Program the approved system.

Task 5. Validate the system through installation and implementation with at least one state transportation department. The NCHRP panel may provide guidance and recommendations on states to work with.

Task 6. Finalize all system documentation and submit all deliverables.

The software and documentation are currently under review. Additionally, another phase of work was initiated to provide enhancements to the software, such as multiuser capabilities, and the enhanced version should be ready by early 1994. A thorough testing of the software by several state highway agencies is anticipated in early 1994. The software and documentation should be available by mid-1994.

Project 12-28(3) FY '85

Fatigue Evaluation Procedures for Steel Bridges

Research Agency:	Case Western Reserve University
Principal Invest.:	Dr. Fred Moses
	Mr. Charles G. Schilling
Effective Date:	July 1, 1985
Completion Date:	September 30, 1987
Funds:	$200,000

The objective of this study was to develop practical procedures that more accurately reflect the actual fatigue conditions in steel bridges, and that can be applied for evaluation of existing bridges or design of new bridges. The procedures were intended to permit determination of fatigue-load ratings and estimation of remaining fatigue life for existing bridges.

Research has been completed and the final report published as: NCHRP Report 299, "Fatigue Evaluation Procedures for Steel Bridges." The report provides recommended revisions to the fatigue evaluation requirements in the AASHTO *Manual for Maintenance Inspection of Bridges,* and to the design requirements in the AASHTO *Standard Specifications for Highway Bridges.*

The recommended fatigue design provisions were adopted by AASHTO in 1988 and issued in 1989 as the AASHTO *Guide Specifications for Fatigue Design of Steel Bridges.*

The recommended fatigue evaluation and remaining life estimation guidelines were adopted by AASHTO in 1989 and were issued as the AASHTO *Guide Specification for Fatigue Evaluation of Existing Steel Bridges.*

Project 12-28(6) FY '85

Distortion-Induced Fatigue Cracking in Steel Bridges

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: October 1, 1985
Completion Date: November 30, 1989
Funds: $250,000

Distortion-induced fatigue cracking has become very prevalent in steel plate girder bridge members. Distortion-induced cracks have occurred in girder webs and gusset plates, usually in the short gaps between the end of a gusset plate or transverse stiffener and the girder flange. NCHRP Project 12-28(6) was initiated with 3 primary objectives. They were to (1) categorize the kinds of fatigue cracks that have occurred because of out-of-plane distortions, (2) develop comprehensive guidelines and criteria that define the conditions that are likely to cause fatigue cracking induced by out-of-plane distortions, and (3) evaluate possible retrofitting techniques for cracked girders that have been subjected to out-of-plane distortions.

Research has been completed and the final report published as NCHRP Report 336, "Distortion-Induced Fatigue Cracking in Steel Bridges." In addition to guidelines on preventing distortion-induced cracking and recommended retrofit techniques, the report also contains recommended revisions to the fatigue design provisions in the AASHTO *Standard Specifications for Highway Bridges.* It is expected that AASHTO will consider the recommended design provisions for adoption in 1992.

Project 12-28(7) FY '86

Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges

Research Agency: Modjeski and Masters
Principal Invest.: Dr. J. M. Kulicki
Effective Date: May 5, 1986
Completion Date: November 30, 1989
Funds: $298,644

The objective of this research was to develop practical guidelines that can be used to assess the effects of corrosion on structural details in steel highway bridges. The research resulted in two manuals for corrosion assessment: a field inspection manual which documents critical details and includes numerous photographs depicting qualitative corrosion severity indices; and a manual providing guidelines for office evaluation and bridge capacity rating due to the corrosion damage identified in the field. In addition, the final report provided recommended corrosion evaluation specification provisions for the AASHTO *Manual for Maintenance Inspection of Bridges.*

The two manuals and recommended specifications were published as NCHRP Report 333, "Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges."

Project 12-28(10) FY '86

Guidelines for Determining Redundancy in Steel Bridges

Research Agency: Lehigh University
Principal Invest.: Dr. J. Hartley Daniels
Effective Date: March 1, 1986
Completion Date: May 31, 1989
Funds: $299,995

The 13th Edition of the AASHTO Standard Specifications for Highway Bridges classifies all two-girder steel highway bridges as nonredundant load path structures. This classification is based on unrealistic concepts widely held by bridge engineers, resulting from the oversimplified assumptions normally used in design, and not on the realistic behavior of the as-built three-dimensional structure.

In this research project, an investigation into the after-fracture redundancy of simple span and continuous, composite and noncomposite steel two-girder highway bridges was conducted. A near full depth fracture was assumed to occur at any position along the length of one of the two girders. The fracture was assumed to penetrate the tension flange and full depth of the web, but not the compression flange. An analytical model was developed consisting of the fractured and unfractured girders together with a redundant bracing system consisting of top and bottom laterals and diaphragms. Results showed that (1) the fractured structure carries dead and live loads as a "pseudo space truss," (2) the after-fracture behavior of the structure is primarily dependent on the strength and stiffness of the redundant bracing system and its connections to the girder flanges, and (3) a properly designed and configured bracing system provides effective and efficient redundancy to a two-girder highway bridge.

Procedures, equations, and worked examples were developed for application to the design of a new or retrofitted redundant bracing system for new or existing bridges and for application to the redundancy rating of a properly configured existing bracing system in terms of AASHTO truck loading.

Research is complete, and the final report has been published as NCHRP Report 319, "Recommended Guidelines for Redundancy Design and Rating of Two-Girder Steel Bridges."

Guidelines are provided for the design and rating of a redundant bracing system including suggested design and

rating loads, allowable stresses, load factors, serviceability criteria, probable fracture locations, strength of connections and allowable fatigue stresses. Guidelines are provided for performing the retrofit of an existing bracing system, for the use of a composite deck as top lateral bracing, for special previsions for continuous two-girder bridges, and for the use of redundant tension cables or rods in lieu of a redundant bracing system for two-girder deck-type bridges and through girder bridges.

Guidelines, procedures, and equations are also presented for the redundancy design or rating of new or existing two-girder steel bridges using the results of a finite element computer analysis of the entire three-dimensional structure. They are intended for bridge engineers who wish to provide redundancy design or rating by computer rather than by using the simplified procedures and equations developed in the remainder of the report.

Project 12-28(11) FY '87

Development of Site-Specific Load Models for Bridge Rating

Research Agency: Imbsen & Associates, Inc.
Principal Invest.: Drs. W. David Liu and C. Allin Cornell
Effective Date: February 9, 1987
Completion Date: March 30, 1990
Funds: $200,000

Throughout the United States bridges are evaluated for their capacity using standard design loads and truck configurations. In some cases bridges are judged to be structurally deficient for the current design loadings and therefore require load posting. The public pays a high price when bridges are posted, either in increased travel time or in costs associated with bridge rehabilitation and replacement. Bridge design loads and design load frequencies are typically used as inputs to the rating process. However, the bridge location determines the actual loads, load frequencies, and truck configurations that an existing bridge will experience. These factors may differ substantially from the current design loadings for which the bridge is presently rated. Data on truck traffic show considerable variation with respect to the functional highway classifications and locations on which they had been collected. More realistic evaluations of bridges may be possible by developing site-specific loading models.

The objective of this research was to develop rational site-specific load models for bridge rating that accurately reflect bridge site characteristics. The project was to also have produced procedures for incorporation of these site-specific models into the bridge rating process in accordance with the AASHTO *Manual for Maintenance Inspection of Bridges.* The models were to consider the bridge location, highway system functional classification, expected vehicle types and configurations, multiple presence of vehicles, peak load spectra, and the degree of legal load limit enforcement.

The final report was not published, but is available for review on a loan basis from the NCHRP.

Project 12-28(12) FY '87

Inelastic Rating Procedures for Steel Beam and Girder Bridges

Research Agency: University of Minnesota
Principal Invest.: Dr. Theodore V. Galambos
Effective Date: September 1, 1987
Completion Date: May 30, 1990
Funds: $241,031

The objective of this research was to develop practical methodologies and procedures for evaluating and rating existing steel bridges based on inelastic analysis. In the development of the inelastic rating procedures, the following factors were considered: plastic moment and shear capacity; permissible permanent deflections; and serviceability of the bridge and bridge deck. In addition, the research considered the frequency and form of inspections, material characteristics, state of deterioration, and other important factors.

The final report was published as NCHRP Report 352. The final report contains the procedures for steel bridge evaluation and rating based on inelastic criteria, recommended specification provisions for consideration by AASHTO, and documentation on several computer programs that were developed during the course of research that assist in the use of the procedures.

Project 12-28(13) FY '87

Nondestructive Load Testing for Bridge Evaluation and Rating

Research Agency: Raths, Raths & Johnson, Inc.,
Principal Invest.: Dr. Suresh G. Pinjarkar
Effective Date: October 4, 1987
Completion Date: September 30, 1989
Funds: $150,000

The objective of this project was to develop guidelines for the nondestructive load testing of highway bridges in order to augment or enhance the analytical bridge rating process. Bridge testing is often used as a research tool and, to a lesser extent, as a method to determine bridge load-carrying capacity. Typical tests require costly equipment and expertise normally not available to bridge owners. From previous bridge tests, it has been noted that many structures possess greater load-carrying capacity than can be predicted by conventional analytical load rating procedures. Therefore, there may be significant gains if standardized test and rating procedures can be developed. This project was initiated with the intent of providing such guidance on methods of load testing and for the incorporation of the load test results into the bridge load capacity rating process.

The research resulted in a report that provided a comprehensive review of literature related to bridge load testing and a summary of the present status of load-test technology. In addition, the report contains a draft procedure for performing some of the more common nondestructive load tests. However, the report did not completely cover all steps necessary for developing a load-rating procedure. NCHRP Project 12-28(13)A, Bridge Rating Through Nondestructive Load Testing, was initiated, in part, because of this.

As much of the material in the agency report will be used in Project 12-28(13)A, it will not be published in the regular NCHRP series. However, copies of the agency report are available on a loan basis from the NCHRP.

Project 12-28(13)A FY '90

Bridge Rating Through Nondestructive Load Testing

Research Agency:	A. G. Lichtenstein & Associates, Inc.
Principal Invest.:	Dr. Abba G. Lichtenstein
Effective Date:	December 17, 1990
Completion Date:	November 30, 1993
Funds:	$227,200

Nondestructive load testing of bridges has been used primarily as a research tool to provide better understanding of the way in which loads are carried by, and distributed through, the bridge structure. In some cases, load testing has been used to assist in the determination of bridge load-carrying capacity. From such tests, some structures have been found to possess greater load-carrying capacity than predicted by conventional analytical load-rating procedures. Load-rating procedures that incorporate load test results have potential for demonstrating higher load capacity for many structures that would otherwise be determined to require load-posting based on conventional analysis alone.

NCHRP Project 12-28(13), Nondestructive Load Testing for Bridge Evaluation and Rating, was initiated in 1987 with the objective of developing guidelines for nondestructive load testing of highway bridges in order to augment the analytical rating process. The project included a comprehensive review of literature related to bridge load testing and resulted in a report summarizing the present status of load-test technology. In addition, the project produced a draft procedure for performing some of the more common nondestructive load tests. However, the project report does not completely cover all steps necessary for developing a load-rating procedure. Specifically, procedures are required for post-test data review and calculations, and for incorporation of the load-test results into the bridge rating process.

In order to allow bridge owners to take advantage of load testing in bridge load rating, a procedure for integrating test results into strength evaluations must be developed in detail. A step-by-step methodology is needed to conduct the load test and translate the test results into a rational bridge load-rating. After this has been done, bridge owners and bridge engineers can be introduced to the advantages of load testing and educated in the methods of bridge evaluation and rating through load testing.

Research is needed to broaden the draft load-test procedures developed in NCHRP Project 12-28(13), to develop a detailed methodology for bridge evaluation and rating based on the results of load testing, and to prepare materials for a training program for bridge owners and bridge engineers that will demonstrate the bridge evaluation and rating process through load testing.

The objective of this project is to develop a manual of recommended procedures for performing bridge load tests and for incorporating load test results into the bridge rating process. Based on the manual, course curriculum and all necessary training materials for a 2-day workshop will be developed to demonstrate and explain bridge load-rating by means of bridge load testing. As a minimum, the project will include the following tasks:

Task 1. Develop practical procedures for integrating the results of bridge load testing into the bridge load-rating process. The procedures shall consider both diagnostic load testing, where the test results must be combined with a mathematical rating analysis, and proof load testing, where the bridge load-rating can be determined directly from the test. Particular attention should be given to identifying and accounting for bridge behavior that might create the appearance of enhanced load capacity during the test but which cannot be relied on under service conditions.

Task 2. Upon completion of Task 1, develop a manual of recommended procedures for bridge evaluation and rating through bridge load testing. This will require augmenting and extending draft procedures related to physical test methods developed primarily in NCHRP Project 12-28(13). The manual must also incorporate procedures for post-test data review and calculations, and load-rating through use of the test results. In addition, pre-test inspection and calculation procedures unique to load testing must also be discussed in the manual.

Task 3. Upon completion of Task 2, develop an outline for a 2-day training course on bridge evaluation and rating through load testing. The course objective is to explain to bridge owners and bridge engineers the steps required to conduct a bridge load test and how to incorporate the test results into the bridge evaluation and rating process. The course will be based on, and is intended to augment, the manual developed in Task 2.

Task 4. Prepare course materials. This will include preparation of an Instructor's Manual, a Student's Manual, and necessary audio and visual aids.

Task 5. Organize and conduct a trial presentation of the course. Recommend a state that would be interested in hosting the course and, after panel concurrence, make arrangements to present it. The NCHRP project panel will assist the contractor in identifying up to 20 participants who will

be invited to attend the course. Participants will include state transportation department personnel along with local bridge officials and consultants. Participants are to critique the course upon its completion.

Task 6. Revise the course materials as necessary on the basis of the course critique.

Task 7. Organize and present the course a second time in a selected state. Again, up to 20 participants will be invited to participate in and critique the course.

Task 8. Finalize all project materials and submit them to the NCHRP.

Two pilot courses on the project material were presented in early 1993. The revised manual and training course materials were submitted in late 1993. In addition, a video and pamphlet on the concept of nondestructive load testing of bridges are under development and should be available in mid-1994.

Project 12-29 FY '85

Design of Simple-Span Precast Prestressed Bridge Girders Made Continuous

Research Agency:	Construction Technology Laboratories/PCA
Principal Invest.:	R. G. Oesterle
Effective Date:	August 26, 1985
Completion Date:	May 31, 1988
Funds:	$241,993

The objectives of this research were to investigate the behavior of precast prestressed bridge girders made continuous by connections using cast-in-place slabs and diaphragms at the piers, and to develop design procedures and guide specifications that can be used to compute elastic, inelastic, time-dependent, and ultimate moments commensurate with the degree of continuity developed by the connections at piers.

The research was completed and the results are reported in NCHRP Report 322, "Design of Simple-Span Precast Prestressed Bridge Girders Made Continuous." The report includes recommendations for positive and negative moment steel at the continuity connection, along with recommendations for changes to the design requirements in the AASHTO *Standard Specifications for Highway Bridges.* The report also includes the description of a simplified computer program that was developed to calculate the time-dependent forces and moments in the girders and at the connections.

Project 12-30 FY '86

Fatigue of Cables in Cable-Stayed Bridges

Research Agency:	Acer Freeman Fox Ltd.
Principal Invest.:	Jolyon A. Gill
Effective Date:	January 13, 1986
Completion Date:	February 12, 1989
Funds:	$124,975

The objectives of this project were to develop criteria and guidelines for the fatigue design of cable stays, anchorages, and saddles, and to develop practical guidelines on material requirements and testing of wires, strands, and cable stays. The research entailed the collection of fatigue data and performance history on cable stays and cable-stayed bridges. Based on this, specification procedures and guidelines suitable for AASHTO were to be developed.

The project produced a draft report with recommended guidelines which were reviewed, but not approved, by the NCHRP project panel. The report will not be published in the regular NCHRP series. The unedited agency report is available from the NCHRP on a loan basis.

Project 12-31 FY '86

Notch Toughness Variability in Bridge Steel Plates

Research Agency:	University of Texas at Austin
Principal Invest.:	Dr. Karl H. Frank
Effective Date:	September 1, 1987
Completion Date:	February 28, 1991
Funds:	$385,000

In 1979, the American Iron and Steel Institute (AISI) published a report of a test program that demonstrated the variability in the impact properties within steel plates based on tests of plates up to 1½ inches in thickness. These data, plus a concern about variability in thick plates of A588 steel, prompted AASHTO to publish an interim specification that resulted in more conservative notch toughness requirements for steel plates that were to be used in Fracture Critical Members (FCM's). Because the toughness requirements in these interim specifications were not based on any test results, AISI began a second study to develop data on plates of larger thicknesses and of grades commonly used as bridge steels.

The second study was completed in 1986 and the results were presented to the AASHTO Subcommittee on Bridges and Structures. The recommendation from the study was to replace the AASHTO interim specification requirements with the previous specification requirements for temperature Zones 1 and 2 (P-frequency testing with removal of the 20°F temperature shift), but to leave the interim Zone 3 requirement as is, because not enough Zone 3 test data were generated to enable a sound conclusion to be drawn. Accordingly, removal of the interim AASHTO notch toughness requirements for Zones 1 and 2 was approved in 1986.

Project 12-31 was initiated with the objective of establishing the variability of CVN impact notch toughness within plates of A572 Grade 50 and A588 steels for plate thicknesses up to 4 in. meeting AASHTO Zone 3 fracture toughness requirements. The research entailed impact testing of more than 4000 charpy specimens machined from numerous

locations in more than 40 plates, which were obtained from four domestic steel producers.

The CVN test results were analyzed statistically to determine if location within a plate was significant with respect to toughness and the overall variability of the plate. The results indicated a significant influence of location in many of the plates. The overall variability of the as-rolled plates was quite large and some plates exhibited pronounced systematic end-to-end and side-to-side variability. Normalized plates had much less variation in toughness.

As a result, a statistically based specification was developed, which accounts for the variability of the CVN tests, and has been submitted to AASHTO for consideration. The project report is published as NCHRP Report 355.

Project 12-33 FY '88, FY '89, FY '90, FY '91, and FY '92

Development of a Comprehensive Bridge Specification and Commentary

Research Agency: Modjeski and Masters
Principal Invest.: Drs. John M. Kulicki and Dennis R. Mertz
Effective Date: July 1, 1988
Completion Date: October 31, 1993
Funds: $1,390,834

Since initial adoption more than 50 years ago, the AASHTO *Standard Specifications for Highway Bridges* have been modified annually by the AASHTO Subcommittee on Bridges and Structures. These specifications are relied on by engineers in state highway agencies, consulting firms, and other organizations responsible for design, construction, and maintenance of bridges. Because of the piecemeal development of the current specifications, extra care is required to avoid inconsistencies, fragmentation, and internal conflicts as individual sections of the specifications are revised each year. This problem is compounded by the fact that a comprehensive commentary is not available to clarify the intent and record the origin of key provision. Some of the specification's shortcommings were corrected by complete editorial revision of the specification in 1984.

The AASHTO Subcommittee on Bridges and Structures recognizes the need for clear, practical specifications based on the best current technology, and state bridge engineers and others devote a substantial amount of time and attention to this end. In recent years, some bridge engineers have called attention to the potential advantages of developing a completely new comprehensive specification and an accompanying commentary.

In response to a high level of interest among state bridge engineers, the AASHTO Subcommittee on Bridges and Structures requested the NCHRP to conduct a study to recommend an outline for an updated AASHTO bridge specification. The scope of the study required an identification of the gaps and inconsistencies in the present specifications and an assessment of the feasibility of basing the revised specifications on a probabilistic load and resistance factor design (LRFD) philosophy.

The study was completed in 1987. It identified many areas where current bridge design technology and design practice are not reflected in the existing AASHTO specifications. Additionally, it recommended that new specifications be developed based on LRFD concepts. The study also recommended that a comprehensive companion commentary be developed.

NCHRP Project 12-33 was initiated in mid-1988 with the objective of developing recommended LRFD-based bridge design specifications and commentary for consideration by the AASHTO Subcommittee on Bridges and Structures. The new specifications are expected to draw heavily from recent developments in bridge design practice throughout the world as well as from recently completed and current bridge research.

Thirteen task groups will be responsible for developing the recommended specifications. The task groups are: general features; loads; analysis and evaluation; deck systems; concrete structures; metal structures; timber structures; joints, bearings, and accessories; foundations; soil-structure interaction systems; moveable bridges; bridge rail; and specification calibration.

Four contractors and 47 consultants have been employed for various tasks on the project. In addition, more than 20 state, federal, and industry engineers have worked on the project on a volunteer basis.

A fourth draft of the LRFD specifications was reviewed by the project panel and the AASHTO bridge community. The AASHTO Highway Subcommittee on Bridges and Structures moved the specifications to ballot at their May 1993 meeting. The final specifications and commentary under AASHTO consideration include a version of both metric units and customary U.S. units.

Project 12-33A FY '88, FY '89, FY '90, and FY '91

Development of a Comprehensive Bridge Specification and Commentary—Timber Structures and Code Calibration

Research Agency: Sensei Engineers
Principal Invest.: Dr. Andrzej Nowak
Effective Date: September 19, 1988
Completion Date: December 31, 1990
Funds: $60,000

NCHRP Project 12-33 was initiated in mid-1988 with the objective of developing specifications for bridge design based on the load and resistance factor design philosophy that can be recommended to AASHTO for consideration for adoption. (See Project 12-33 writeup for more detail.) A number of agencies and individuals were employed during

the course of the project for various tasks and responsibilities.

The agency employed on Project 12-33A was directed by the Principal Investigator on Project 12-33, Dr. John Kulicki. Sensei Engineers was responsible for coordinating the activities of the task groups on wood design and specification calibration. However, the contract for Sensei Engineers was terminated in December 1990, and the responsibility for the work was transferred to Dr. Nowak acting as a consultant to the Transportation Research Board.

Project 12-33B FY '88, FY '89, FY '90, and FY '91

Development of a Comprehensive Bridge Specification and Commentary—Concrete Structures

Research Agency: Imbsen & Associates, Inc.
Principal Invest.: Mr. Robert C. Cassano
Effective Date: September 19, 1988
Completion Date: March 31, 1992
Funds: $125,500

NCHRP Project 12-33 was initiated in mid-1988 with the objective of developing specifications for bridge design based on the load and resistance factor design philosophy that can be recommended to AASHTO for consideration for adoption. (See Project 12-33 writeup for more detail.) A number of agencies and individuals were employed during the course of the project for various tasks and responsibilities.

The agency employed on Project 12-33B acted under the direction of the Principal Investigator on Project 12-33, Dr. John Kulicki. Imbsen & Associates, Inc. was responsible for coordinating the activities of the task group on concrete structures design.

Project 12-33C FY '88, FY '89, FY '90, and FY '91

Development of a Comprehensive Bridge Specification and Commentary—Soil-Structure Interaction Systems

Research Agency: D'Appolonia
Principal Invest.: Dr. James L. Withiam
Effective Date: July 24, 1989
Completion Date: December 31, 1991
Funds: $83,832

NCHRP Project 12-33 was initiated in mid-1988 with the objective of developing specifications for bridge design based on the load and resistance factor design philosophy that can be recommended to AASHTO for consideration for adoption. (See Project 12-33 writeup for more detail.) A number of agencies and individuals were employed during the course of the project for various tasks and responsibilities.

The agency employed on Project 12-33C acted under the direction of the Principal Investigator on Project 12-33, Dr. John Kulicki. D'Appolonia was responsible for developing specification provisions relating to soil-structure interaction systems such as culverts, anchored walls, mechanically stabilized earth walls, and prefabricated modular walls.

Project 12-34 FY '88 and FY '89

Update of AASHTO Standard Specifications for Highway Bridges: Division II—Construction

Research Agency: Imbsen & Associates, Inc.
Principal Invest.: Robert C. Cassano
Effective Date: October 19, 1987
Completion Date: October 18, 1989
Funds: $200,000

The AASHTO *Standard Specifications for Highway Bridges* consists of two sections: Division I—Design, and Division II—Construction. Both sections should play an important role in bridge design and construction. These sections, along with additional guide and material specifications, aid public agencies in the preparation and use of their standard specifications and contract documents.

The objective of this project was to develop recommendations for a revised Division II-Construction specification that would reflect current practice in highway bridge construction. In addition, a companion commentary explaining the background and intent of the various provisions was also developed.

The project was completed and the recommended specifications and commentary were submitted to AASHTO in 1989. The recommended specifications provided a complete re-write of Division II. AASHTO adopted the revised specifications and commentary in 1990, and they were subsequently issued with the 1991 Interims to the *Standard Specifications for Highway Bridges.*

Project 12-35 FY '88

Recommended Specifications for the Design of Foundations, Retaining Walls, and Substructures

Research Agency: D'Appolonia
Principal Invest.: Dr. James L. Withiam
Effective Date: January 4, 1988
Completion Date: July 3, 1989
Funds: $99,588

The AASHTO *Standard Specifications for Highway Bridges* (14th Edition, 1989) are used for the design of highway bridges by many public and private agencies in the United States and abroad. Sections 4, 5, and 7 of Division I—

Design, provide guidance for the design of highway bridge foundations, retaining walls, and substuctures.

The objective of this project was to develop recommended revisions to Sections 4, 5, and 7 of the AASHTO *Standard Specifications for Highway Bridges* to reflect the current practice and state of the art in geotechnical engineering and substructure design.

The project was completed and the recommended specifications and commentary were submitted to AASHTO in 1989. The recommended specifications provided a complete re-write of Sections 4, 5, and 7 to the design specifications. AASHTO adopted the revised specifications and commentary in 1990, and they were subsequently issued with the 1991 Interims to the *Standard Specifications for Highway Bridges.*

Project 12-36 FY '91

Redundancy in Highway Bridge Superstructures

Research Agency:	City University of New York
Principal Invest.:	Drs. Michel Ghosn and Fred Moses
Effective Date:	April 8, 1991
Completion Date:	November 16, 1993
Funds:	$200,000

The AASHTO *Standard Specifications for Highway Bridges* requires consideration of redundancy when designing steel bridge members. There is limited guidance in the specifications concerning when a structure is, or is not, redundant. The specification states that a structure is nonredundant ". . . when the failure of a single element could cause collapse." The specification does not, however, define collapse, which has led to a large variation in specification interpretation and bridge analysis. In addition, the specification does not require consideration of redundancy in the design of bridges other than steel.

Redundancy can be present in the superstructure, substructure, or in the entire bridge. In addition, according to the 1986 FHWA report, *Inspection of Fracture Critical Bridge Members,* there can be load path, structural, or internal redundancy. Guidance is presently lacking for each of these types of redundancy.

A new bridge design specification and bridge evaluation manual are under development for consideration by AASHTO; both are based on Load and Resistance Factor Design (LRFD) methodology. The purpose of using LRFD is to achieve more uniform reliability for all materials and structural systems used in bridge design and load capacity rating. To achieve this, consideration must be given to the varying degrees of redundancy inherent in different bridges. For example, bridges can be classified, at a minimum, as either nonredundant, dual-load-path redundant, or multiple-load-path redundant.

Research is needed to develop a framework for consideration of redundancy in bridge design and load capacity evaluation. Proposed criteria should be based on levels of serviceability rather than collapse. For example, serviceability could be considered at the following levels: a structure that will remain undamaged under all traffic loads and conditions; a damaged structure that can continue to carry normal traffic but that can be repaired; and a severely damaged structure that will allow existing traffic to safely leave the bridge but will require closure.

The objective of this study is to develop a framework for considering redundancy in design and load capacity evaluation of highway bridge superstructures, possibly in the form of a matrix of resistance factor modifiers for varying types of redundancy and levels of serviceability. This framework shall be limited to common steel and concrete bridges.

It is anticipated that the research will include the following tasks:

Task 1. Review and assess *relevant* current practice, performance data, and research findings. This information shall be assembled from the technical literature and the unpublished experience of bridge engineers, consultants, researchers, and other bridge owners.

Task 2. Develop draft definitions for levels of serviceability and types of redundancy, considering those discussed in the Research Problem Statement as a starting point. The definitions must provide a methodology to quantify the various levels and types.

Task 3. Outline a framework for consideration of redundancy in the design and load capacity evaluation of highway bridge superstructures. If the framework includes a matrix of resistance factor modifiers, identify where sufficient data exist to develop the factors. Where data are lacking, identify how the factors will be developed.

Task 4. Prepare an interim report summarizing the work performed in Tasks 1 through 3. The interim report must also include a detailed work plan for the remainder of the project and must be submitted within 8 months of the start of the project. NCHRP approval of the interim report and detailed work plan will be required prior to initiation of the remaining project tasks.

Task 5. Conduct field investigations, analytical studies, or laboratory studies, as appropriate, in accordance with the detailed work plan presented in the interim report.

Task 6. On the basis of the Task 5 studies and other information that may be available, finalize the definitions and framework. The framework must be developed in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures.

Task 7. Identify additional research needed for factors associated with the framework that can not be adequately defined at this time.

Task 8. Prepare and submit a final report documenting all work on the project.

The draft final report was submitted in late 1993 and is

under review. If the report is published in the regular NCHRP report series, it should be available in mid-1994.

Project 12-37 FY '92

Transverse Cracking in Newly Constructed Bridge Decks

Research Agency: Wiss, Janney, Elstner Assoc., Inc.
Principal Invest.: Paul D. Krauss
Effective Date: January 27, 1992
Completion Date: January 27, 1995
Funds: $350,000

Concrete bridge deck cracking is a prevalent problem in the United States. Cracking has been reported to occur in a variety of geographical locations and climates and in many bridge superstructure types. Cracks may occur transversely, longitudinally, or randomly (map or alligator type crack patterns) in the deck.

Transverse and longitudinal cracking in newly constructed bridge decks is of significant concern. Such cracks may constitute a critical break in the first line of defense for the integrity of the bridge. These cracks may allow water, deicing chemicals, and other deleterious materials to penetrate into and through the deck. Problems caused by such cracks may include accelerated corrosion of reinforcing steel, extensive deterioration of the concrete, damage to structural members and components beneath the deck, and the unsightly appearance of cracks and efflorescence. These problems may reduce the service life of bridge decks, increase costs for bridge maintenance and repair, and compromise long-term structural integrity of the bridge.

In recent years, there has been a significant amount of research on the causes and prevention of longitudinal cracking. Therefore, research is needed to determine the major factors that contribute to transverse cracking in newly constructed bridge decks. The research should address all factors related to design, materials, and construction and develop recommended guidelines for use in bridge design and construction that can prevent transverse cracking in bridge decks.

The objectives of this research are to determine the major factors or combination of factors that contribute to transverse deck cracking in newly constructed bridge decks, and to develop specific recommendations to prevent such cracking. The research will be limited to conventionally reinforced bridge decks constructed on either simple or continuous span superstructures.

It is anticipated that the research will include at least the following tasks:

Task 1. Collect and review relevant domestic and foreign literature, research findings, performance data, and current practices relative to the causes and prevention of transverse cracking in bridge decks. This information must be assembled not only from published literature, but also from unpublished reports that may exist within transportation and research agencies.

Task 2. Summarize and evaluate the information generated in Task 1 and any specific experience the research team may have with this problem. Determine the extent of the problem (number of structures nationwide, correlations to bridge type, construction practices, etc.).

Task 3. Define the characteristics (crack size, spacing, etc.) of transverse cracking that would be expected to lead to the problems noted earlier. Provide rationale to support these characteristics.

Task 4. Identify, evaluate, and rank the factors or combination of factors that contribute to transverse cracking in newly constructed bridge decks broken down by the categories of design, materials, and construction.

Task 5. Present the findings of Tasks 1 through 4 in an interim report to be submitted not later than 9 months after initiation of the study. The interim report shall contain the comprehensive list ranking all factors from Task 4 with its supporting rationale. The interim report shall also contain a detailed research plan for the remainder of the study. NCHRP approval of both the interim report and detailed research plan will be required before research on remaining tasks may commence.

Task 6. Conduct field investigations, analytical studies, and/or laboratory investigations as appropriate in accordance with the approved detailed research plan from Task 5. Quantify the effects of the principal contributing factors and verify or modify the ranking established in Task 4.

Task 7. Based on the results of Task 6, prepare a guide document with recommendations for the prevention of transverse cracking in newly constructed bridge decks.

Task 8. Prepare and submit a final report containing the research findings, the proposed guide document, and recommendations for further research.

Research on Tasks 1 through 4 has been completed, and the Phase I report has been reviewed and approved by the project panel. Work on Task 6 is proceeding on schedule.

Project 12-38 FY '93

Improved Design Specifications for Horizontally Curved Steel Girder Highway Bridges

Research Agency: Auburn University
Principal Invest.: C. H. Yoo
Effective Date: January 1, 1993
Completion Date: March 31, 1995
Funds: $300,000

The AASHTO *Guide Specifications for Horizontally Curved Highway Bridges* (hereafter referred to as "Guide Specifications" or "Guide") was initially issued in 1980 and is based on research performed in the early 1970s. The *Guide Specifications* include design provisions for curved steel I-

girder and composite box-girder bridges using either working-stress design or load-factor design criteria.

More than 12 years of design and construction experience with the *Guide Specifications* has demonstrated some major deficiencies. In its present form, the *Guide* is disjointed and difficult to follow. The commentary is incomplete and lacks needed detailed explanation regarding the development of many of the provisions. Many provisions are overly conservative, and many are difficult to implement. Other provisions lend themselves to misinterpretation, which may lead to uneconomical structures or structures with factors of safety less than intended. Other critical deficiencies include: lack of fabrication and erection provisions; insufficient guidance on analytical procedures for both preliminary and final design; lack of guidance on which curvature effects can be safely ignored in bridges with large radii of curvature; and design criteria apparently inconsistent with that for current straight-girder bridges.

To address these needs, the Federal Highway Administration has initiated a comprehensive multi-year program of analytical and experimental research on horizontally curved steel bridges. While awaiting the findings of the FHWA research program, there is a pressing need for improved specifications based on current practice and technology. Research is therefore needed to develop an improved specification that can be implemented as soon as possible. It is anticipated that this improved specification will be updated later by AASHTO on the basis of results produced by the FHWA research program.

The objective of this project is to develop a revised *Guide Specifications for Horizontally Curved Highway Bridges,* based on current practice and technology, that can be recommended to AASHTO for consideration for adoption. The revised *Guide Specifications* shall be applicable to the design, fabrication, and erection of steel I- and box-girder bridges and shall include both working-stress and load-factor design methods.

The research shall include the following tasks:

Task 1. Collect and review relevant domestic and foreign literature, research findings, and current practices related to the design, fabrication, and erection of horizontally curved steel I- and box-girder bridges. Much of this material will be compiled under the existing FHWA project and will be available at the start of this project.

Task 2. Survey owners, designers, fabricators, and erectors of curved steel bridges, to identify successful practices and problems that have occurred in design, fabrication, erection, and service.

Task 3. Evaluate the information assembled in Tasks 1 and 2, and prepare a comprehensive list of, and rationale for, revisions that can be recommended based on current practice and technology. Discuss any remaining limitations, which cannot be adequately addressed without further analytical and experimental work, noting specific research needs to better model horizontally curved girder bridge behavior and to define improved limit-state design criteria.

Task 4. Prepare a detailed outline for the revised *Guide Specifications,* which includes a discussion of the intent and contents of each section.

Task 5. Document the findings of Tasks 1 through 4 in an interim report to be submitted not later than 8 months after initiation of the study. NCHRP approval of the interim report will be required before commencing Task 6. Two months will be required for review and approval of the interim report.

Task 6. Prepare a first draft of the revised specifications and commentary, in a format suitable for consideration by the AASHTO Highway Subcommittee on Bridges and Structures.

Task 7. Demonstrate the use of the proposed specifications with practical design examples. The examples shall be a fully explanatory application of the proposed code, demonstrating load generation, computation of moments, shears, torsional effects and reactions, and application of all provisions at critical sections throughout the bridge. Example problems shall cover I- and box-girder multi-span continuous bridges with both radial and skewed supports.

Task 8. Submit the draft specifications and example problems. Three months will be required for review by the NCHRP and AASHTO.

Task 9. Prepare and submit a second draft of the specifications and example problems revised, as necessary, based on the NCHRP and AASHTO review comments. The second draft and example problems will also be reviewed by the NCHRP and AASHTO and will also require 3 months to complete.

Task 10. Prepare and submit a final report containing: the research findings; the proposed *Guide Specifications,* including commentary and design examples, revised in accordance with the review comments generated after Task 9; and recommendations for further research.

An interim report that documented the findings of Tasks 1 through 3 was reviewed in late 1993. Research is continuing with the development of draft specifications and commentary, as well as design examples.

Project 12-39 FY '93

Design Specifications for Debris Forces on Highway Bridges

Research Agency:	University of Louisville
Principal Invest.:	
Effective Date:	March 1, 1993
Completion Date:	May 31, 1995
Funds:	$299,977

Along with other factors, forces due to debris should be considered in the design of bridges over water. Section 3.18 of the current AASHTO *Standard Specifications for High-*

way Bridges states, "All piers and other portions of structures that are subjected to the force of flowing water, floating ice, or drift shall be designed to resist the maximum stresses induced thereby." Unfortunately, this is the limit of the guidance provided in the specifications to the bridge designer for determination of debris (drift) forces. In its report on the investigation of the 1989 collapse of the Harrison Road Bridge in Ohio, the National Transportation Safety Board also recognized the need for more effective guidance in the AASHTO specifications, and recommended that improved specifications for debris loading on bridges be developed.

At present, there is insufficient information available to quantify the impact, drag, and hydrostatic forces due to debris. Rational design specifications can not be developed without this information. Research is needed to develop methods for estimating maximum debris loads and improved specifications based on these methods.

The objective of this research is to develop practical design specifications and supporting commentary for the determination of impact, drag, and hydrostatic forces on bridge piers and superstructures due to debris.

NOTE: A 3-year joint study by the Federal Highway Administration (FHWA) and the U.S. Geological Survey (USGS) will characterize debris at bridges as a function of stream reach and basin characteristics, and debris size and type. The FHWA/USGS study, which was initiated in March 1992, has as its initial task a comprehensive literature review. Results of this literature review will be provided to the selected researcher at the start of this project. Other relevant data generated by the FHWA/USGS study will be provided to the selected researcher as it becomes available.

The research conducted under Project 12-39 shall include the following tasks:

Task 1. Collect and review relevant domestic and foreign literature, research findings, and current practices related to design for hydrodynamic and debris-induced forces on bridges. Some of this material will be compiled under the joint FHWA/USGS project currently in progress, and will be available at the start of this project. Collect and review other relevant material related to lateral forces, including ice forces and vessel impact.

Task 2. Develop analytical methods to quantify impact, drag, and hydrostatic forces on bridge piers and superstructures due to debris. Compile and integrate these methods into a procedure that can be used as the basis for specifications to calculate significant debris forces on bridges. Note: the procedure developed here should consider debris size, type, and accumulation characteristics. However, the FHWA/USGS study will eventually provide formal maximum definitions for design purposes.

Task 3. Present the findings of Tasks 1 and 2 in an interim report to be submitted within 10 months after initiation of the research. The report shall include a discussion of the proposed procedure, emphasizing those areas where experimental verification is needed. It shall also include a detailed research plan for the experimental work needed to perform the verification. NCHRP approval of the interim report and detailed research plan will be required before research on the remaining tasks may commence.

Task 4. Conduct field investigations, laboratory studies, or both, as appropriate in accordance with the detailed research plan from Task 3. The purpose of these experiments will be to calibrate and validate the analytical methods developed in Task 2.

Task 5. Based on the experimental results, revise the analytical methods as required. Develop specifications and supporting commentary for debris forces in a format suitable for consideration by AASHTO. Demonstrate the use of the proposed specifications with practical example problems.

Task 6. Prepare and submit a final report containing the research findings, the proposed specifications and commentary, and recommendations for further research.

An interim report documenting the findings of Tasks 1 and 2 was submitted in late 1993 and is under review.

Project 12-40 FY '94

Fatigue Criteria for Modular Bridge Expansion Joints

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	27 months
Completion Date:	
Funds:	$335,000

Many premature failures of modular bridge expansion joints can be attributed to fatigue problems. Expansion joints are subjected to more load cycles than other superstructure elements, but the load types and magnitudes, and fatigue-stress ranges that are applied to these joints are not well defined. Additionally, sufficient data are not available on field measurements and laboratory testing of fatigue-critical joint details. The AASHTO *Standard Specifications for Highway Bridges* do not include fatigue design criteria for these joints; at present, modular bridge expansion joints in the United States are designed by their suppliers using proprietary techniques, apparently without sufficient regard for fatigue.

With variations in the proprietary design techniques, inadequate information on the effects of cyclic loading, and no specifications for guidance, it is difficult for designers to ensure the satisfactory performance and long-term durability of these joints. Therefore, research is needed to provide information, including performance-based specifications with commentary, for guidance on the fatigue-resistant design of modular bridge expansion joints.

The objective of this research is to develop performance-

based specifications and supporting commentary for the fatigue-resistant design of modular bridge expansion joints for consideration by the AASHTO Highway Subcommittee on Bridges and Structures.

It is anticipated that the research will encompass at least the following tasks:

Task 1. Review relevant practice, performance data, existing specifications, and research findings from both foreign and domestic sources. This information shall be assembled from both technical literature and unpublished experiences of engineers, bridge owners, fabricators, and manufacturers of modular bridge expansion joints.

Task 2. Identify critical parameters (e.g., load types, roadway and bridge geometry, design details, and wheel distribution) that influence fatigue performance of modular bridge expansion joints. Identify the extent of, and predominant causes for, fatigue failure of in-service joints.

Task 3. Conduct field tests of both single-support-bar and multiple-support-bar modular bridge expansion joints to (1) assess behavior under static and dynamic truck loading and (2) define critical stress locations.

Task 4. Submit an interim report that documents the results of Tasks 1 through 3 and proposes a detailed work plan for the remainder of the project. Following project panel review of the interim report, meet with the panel to discuss the interim report and the remaining tasks. NCHRP approval of the interim report will be required before proceeding with the remaining tasks.

Task 5. According to the approved work plan, conduct laboratory investigations to determine fatigue criteria, some of which may correlate with AASHTO categories for fatigue-critical details. Compare the results with appropriate analytical models.

Task 6. Based on the results of Tasks 1 through 5, develop (1) a design formula that can be used as the basis for recommended specifications that consider the design life (e.g., 25 years) of bridge expansion joints; (2) recommended performance-based specifications and commentary, with design examples, for the fatigue-resistant design of modular bridge expansion joints; and (3) recommended fatigue-testing acceptance procedures for use by highway agencies. The specifications shall be prepared in a format suitable for consideration by AASHTO.

Task 7. Submit a final report describing the entire research project. Include the recommended specifications with commentary, the design examples, and the recommended fatigue-testing acceptance procedures as appendices.

Project 12-41 FY '94

Rapid Replacement of Bridge Decks

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (36 Months)
Completion Date:
Funds: $500,000

With increasing highway traffic, motorists are becoming more intolerant of delays during rehabilitation of bridge decks. Their impatience also increases the risk of accidents. Methods of bridge-deck replacement that allow repair work to be completed at night or during other periods of low traffic, and methods that reduce the total time for reconstruction, improve public acceptance, reduce accident risk, and yield economic and environmental benefits.

A number of techniques for expediting replacement of bridge decks have been introduced in recent years; however, research is needed to evaluate existing rapid bridge-deck replacement methods and to develop better procedures and new superstructure designs for future rapid deck replacement of conventionally reinforced concrete decks on steel or concrete girders using both conventional and new materials, designs, and construction techniques.

The objectives of this research are to (a) develop optimized systems for rapid deck replacement and (b) recommend design guidelines and details for new superstructures that can facilitate future rapid deck replacement.

To accomplish these objectives, the following two research phases will be conducted:

Phase I: (1) Collect and review domestic and foreign literature, research findings, performance data, and current practices relative to the rapid replacement of conventionally reinforced concrete bridge decks. This information must be assembled from published literature, unpublished reports, contact with state transportation agencies, and other sources. (2) Summarize the information gathered in Task 1 and identify factors for evaluating the advantages and disadvantages of existing bridge-deck replacement systems. Develop a matrix of these factors to provide a basis for comparing these systems. Discuss the advantages and disadvantages of each system and identify promising system(s) for rapid bridge-deck replacement. (3) Describe improvements that could be made to the promising systems identified in Task 2, and propose new concepts that should be investigated for use in rapid-bridge deck replacement. Evaluate these improvements and concepts using the factors identified in Task 2, and discuss the features of each system; especially those features that cannot be adequately evaluated without further analytical or experimental investigation. (4) Develop concepts for new superstructure designs and construction details that would facilitate efficient and cost-effective future rapid deck replacement. Discuss the features of each proposed concept; especially those features that cannot be adequately evaluated without further analytical or experimental investigation. (5) Develop a detailed work plan for Phase II that encompasses analytical and/or experimental investigations for evaluating the suitability and long-term performance of the improvements and concepts identified in Tasks 3 and 4. (6) Prepare an interim report that (a) documents the research performed in Tasks 1 through 5 and (b) provides a work plan for the Phase II portion of the project, describing rationale, methods, schedule, budget, and other details. Following review of the interim report by the project panel, the research

team will be required to make a presentation to the project panel.

Phase II: (7) Execute the investigations approved in Task 6 for evaluating the proposed improvements and concepts pertaining to replacement of bridge decks. Based on the results of this work, identify the optimum improvements and feasible concepts, and recommend a plan for further evaluation in trial installations. For these improvements and concepts, provide specifications, drawings, construction sequencing, and other details required to facilitate the construction, monitoring, and evaluation of each proposed system. (8) Execute the investigations approved in Task 6 for evaluating the proposed new superstructure designs. Based on this work, recommend guidelines for new superstructure designs and construction details that would facilitate efficient and cost-effective future rapid deck replacement. The guidelines shall be presented in a format suitable for consideration and adoption by AASHTO. (9) Submit a final report that documents the entire research effort. The report shall include practical recommendations for rapid bridge-deck replacement on existing structures and superstructure designs that will facilitate future rapid deck replacement. In addition the report shall contain an implementation plan for moving the results of this research into practice. Following review and comment by the project panel, the research team will be expected to make a presentation on the project findings to the AASHTO Subcommittee on Bridges and Structures.

AREA 13: EQUIPMENT

(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)

AREA 14: MAINTENANCE OF WAY AND STRUCTURES

Project 14-7 FY '87

Interactive Microcomputer Network for Innovative Maintenance Operations

Research Agency: Woodward-Clyde Consultants, Inc.
Principal Invest.: Fred Reid
Effective Date: September 1, 1987
Completion Date: June 30, 1991
Funds: $82,819

Innovations in areas of materials, equipment, and methods are continuously being developed by maintenance operations personnel. These innovations are rarely communicated beyond organizational boundaries. Today operational-level personnel often are not aware that their innovations could solve problems in other organizations and they do not have a comfortable way for transferring this information. Consequently, other operations personnel do not have access to knowledge that could increase their productivity. A data base identifying these innovations, and shared within and between states, is needed that would be available to the "man in the field."

The objective of this project is to develop a system design for a cost-effective microcomputer-oriented network to create and to access a dynamic data base of innovations in highway maintenance operations. The users are intended to be the operational-level maintenance personnel in highway agencies for first and second level supervisors.

Key characteristics of the system are that it be menu-driven for data-base entry and retrieval and other associated functions. It is to be networked using a modem or other cost-effective communication link. As a starting point it is planned that the menu be structured with maintenance elements as described in NCHRP Report 273, "Maintenance Levels of Service Guidelines," and that it include equipment as a major category.

Key deliverables of the project will be a report describing the system design and a plan for a prototype installation to evaluate the feasibility and practicality of the system.

Research has been completed, and efforts are underway to prepare a Research Results Digest from the final report.

Project 14-8 FY '87

Chip Seal Coats for High-Traffic-Volume Asphalt Concrete Pavements

Research Agency: Intermountain Research Foundation (University of New Mexico)
Principal Invest.: Dr. T. S. Shuler
Effective Date: July 6, 1987
Completion Date: October 5, 1990
Funds: $80,078

Chip seal coats, usually applied to low-volume roads, are used to extend pavement service life by reducing water infiltration and improving skid resistance. The use of chip seal coats on high-traffic-volume roads has had limited application because of unknown cost effectiveness, potential windshield damage, unsatisfactory results because of lack of adherence to sound engineering principles, and traffic disruption during construction. However, chip seal coats may be suitable on roads with relatively high volumes, in the vicinity of 20,000 vehicles per day on four-lane roads, thereby postponing the need for overlays. Research is needed to investigate the causes and provide solutions to the problems that discourage the use of chip seal coats on high-volume roads.

The objective of this research is to develop a workable system for applying chip seal coats to high-traffic-volume asphalt concrete pavements as a cost-effective alternative to asphalt concrete overlays. For purposes of this project high traffic volumes are those in excess of 7,500 vehicles per day in one direction on a four-lane highway.

The literature review was completed, and an annotated

bibliography was submitted. A poll of experienced personnel was conducted to (1) determine the extent of use of chip seals on high volume pavements, (2) determine materials, design methods, procedures, performance, etc., where chip seals are used, and (3) understand and quantify the effects of various factors on chip seal performance. The Interim Report for the project was submitted and approved by the project panel. One field test project in Tulsa, OK, on U.S. 169, was successfully accomplished. Four different treatments were investigated, along with two speeds of the pilot car.

The project's Principal Investigator has accepted a new position as Research Director with the Asphalt Institute, and a request was made by IRF to transfer responsibility for completion of the project to the Asphalt Institute. The request was approved by the project panel, and the contract with Intermountain Research Foundation has been finalized.

Project 14-8A FY '87

Chip Seal Coats for High-Traffic-Volume Asphalt Concrete Pavements

Research Agency: The Asphalt Institute
Principal Invest.: Dr. T. S. Shuler
Effective Date: January 1, 1991
Completion Date: December 31, 1992
Funds: $159,922

This contract was initiated to transfer the responsibility for research in this area from Intermountain Research Foundation, Inc. to the Asphalt Institute. This was done at the request of the research agency after the project's Principal Investigator accepted a new position with the Asphalt Institute. The project panel has agreed to this transfer and approved the proposal from the Asphalt Institute to complete all work remaining on the contract.

Please see the project description under Project 14-8, above. The research has been completed with a total of four field test projects conducted and evaluated. The preliminary draft of the final report has been submitted and reviewed by the project panel. The Principal Investigator will complete the revised final report by the end of the year.

Project 14-9(1) FY '90

Effective Maintenance Budget Strategies

Research Agency: The Urban Institute
Principal Invest.: Arlee Reno
Effective Date: November 15, 1989
Completion Date: March 15, 1994
Funds $300,000

The present condition of highway infrastructure in many parts of the United States is testimony that funding levels have not been adequate for maintenance. Effective communication of budget requests to chief administrative officers (CAOs), highway and transportation commissions, and legislative bodies is a key to funding highway maintenance operations at levels that will preserve investment in the highway system, minimize long-term replacement and user costs, and provide user services. However, many state highway agencies have not been successful in communicating such maintenance needs. This may be due to a number of factors, including consideration that benefits from maintenance operations are much less immediately visible to the public than those from construction, and the apparent inability of maintenance managers to convey to executive and legislative bodies the quantifiable benefits of adequate maintenance funding.

There is a critical need for appropriate guidelines to aid maintenance managers in developing effective maintenance budgeting strategies. Although maintenance will continue to compete with other transportation programs, the use of such guidelines will facilitate better recognition of maintenance needs, in the context of total transportation budget requirements, and it will increase the probability that the highway infrastructure will be preserved.

The objectives of the study are to (1) identify current practices in formulating and justifying state highway maintenance budgets; (2) assess the strategic usefulness of the various approaches to achieve funding levels consistent with preserving and operating the highway system at acceptable standards; and (3) develop guidelines for effectively conveying maintenance budget requests to CAOs, highway and transportation commissions, and legislative bodies.

This project includes the following tasks:

Task 1. Identify key elements in developing and presenting maintenance budgets in an effective manner; in other words, focus on questions that need to be answered and how they should be addressed in successfully presenting maintenance budgets to CAOs, highway and transportation commissions, and legislative bodies.

Task 2. Survey and compare, in terms of similarities and differences, the methods currently used by state highway agencies to develop maintenance budgets and the procedures followed to justify and communicate budget needs to executive and legislative bodies. As part of this survey, variations from the definition of maintenance found in the *AASHTO Maintenance Manual* (1987) should be highlighted. The researchers shall have the survey instrument reviewed and approved by the project panel and, then, pilot tested in several states prior to distribution to all state DOTs. The researchers shall, in addition, select a sample of at least 10 states, including states using dedicated funds and states using general funds, to conduct in-depth field visits in order to identify in detail the best practices.

Task 3. Review and analyze the survey results to assess the effectiveness of various state maintenance budget request strategies, in relation to the key elements identified in Task 1. The assessment should include, but not be limited to, an

identification of the strengths and weaknesses of existing practices, how legislative and public feedback is obtained, and how innovative or creative strategies are used.

Task 4. Document the findings of the previous tasks in an interim report. In addition, formulate a detailed work plan for the remaining tasks and incorporate this plan into the interim report. Submit the interim report for review by the NCHRP project panel. Soon after distribution of the interim report, a meeting between the research team and the NCHRP project panel will be scheduled for the purpose of providing the panel members the opportunity to interact with the researchers in a detailed discussion on the contents of the interim report. NCHRP approval of the interim report will be required before proceeding with the remaining tasks.

Task 5. Identify existing analytical techniques and data sources that can be used to determine road user costs, safety costs, environmental impacts, tort liability, measured maintenance service levels, and other consequences of alternative maintenance budgets. This effort should draw primarily on published literature. Suggest procedures that can integrate and adapt the analytical techniques and data identified to generate information that can be used as enhancements to maintenance budgeting practices.

Task 6. Identify ISTEA requirements for management systems and institutional changes, review state actions to comply with these requirements, and develop guidelines for the use of management system data in the maintenance budgeting strategies.

Task 7. Evaluate the results of recently completed NCHRP projects on maintenance activities and incorporate the findings into the guidelines and procedures for maintenance budgeting strategies.

Task 8. On the basis of the work performed in the previous tasks, develop guidelines for alternative strategies that a maintenance manager can consider in effectively formulating, presenting, and defending maintenance budgets. The researchers shall also present the results of this research effort at a meeting of the AASHTO Highway Subcommittee on Maintenance.

Task 9. Prepare a final report documenting the research.

The preliminary draft final report has been submitted and is currently under review.

Project 14-9(2) FY '90

Incorporation of Maintenance Considerations in Highway Design

Research Agency:	Daniel, Mann, Johnson, and Mendenhall
Principal Invest.:	Turan Ceran and Robert B. Newman
Effective Date:	February 28, 1990
Completion Date:	March 31, 1992
Funds:	$190,000

Inadequate consideration for maintenance during design was recognized some years ago in the Iowa Highway Maintenance Study (1959–1960, *HRB Special Report 65*). The problem persists to this day and is a contributing cause of increased maintenance work and inconvenience to highway users.

A process is needed for designers to be systematically aware of the maintenance implications of their designs. Designs must be developed and evaluated, recognizing a number of assumptions affecting maintenance operations and requirements. Knowing the implications of these assumptions will permit the documentation of maintenance needs to ensure that maintenance personnel, equipment, materials, and funds will be available when needed.

Designers must also be aware of design details that create maintenance problems and be willing to incorporate improvements to increase the "maintainability" of highway components. There is a need to specifically identify and communicate maintenance problems that can be addressed through better design. This need is gaining importance because of the greatly increased volume of traffic that makes it difficult to close traffic lanes for routine maintenance work. Although it would be desirable to design highway components (such as pavements, bridges, drainage features, and roadside appurtenances) with zero-maintenance requirements, this is not usually possible; therefore, designs should be developed to ensure maintainability at minimum life-cycle costs.

Accordingly, research was undertaken to address three objectives: (1) determine the current practice of incorporating maintenance concerns in the highway design process and identify successful techniques, weaknesses, and needed improvements; (2) recommend a design process that will achieve explicit recognition of the maintenance implications of designs; and (3) list and describe design details that create maintenance problems and suggest improvements to overcome them. These objectives have been accomplished through a research approach that involved a literature search, a survey of practices, interviews in selected state transportation agencies, and a demonstration.

The research results have been published as NCHRP Report 349, "Maintenance Considerations in Highway Design."

Project 14-9(3) FY '90

Maintenance Contracting

Research Agency:	Bergstralh-Shaw-Newman, Inc.
Principal Invest.:	Robert B. Newman
Effective Date:	March 12, 1990
Completion Date:	September 11, 1991
Funds:	$150,000

Highway departments are challenged by increasing levels-of-service demands and the deteriorating infrastructure at a time of constrained resources (funds, equipment,

materials, and personnel). As the resulting workload enlarges, the contracting of maintenance activities is being used as an alternative to the expansion of in-house resources. However, limited in-house resources may not be the only reason for engaging in contract maintenance. Decisions for contracting can also be based on such factors as the need for specialized equipment and expertise, more cost-effective procedures or techniques, better quality, public demand for new services, statutory requirements, agency policies, seasonality of work, and contractor availability.

Most state highway departments have gained experience in various contracting relationships with private industry and, in some instances, other governmental agencies that collectively include many aspects of performing highway maintenance. Contract maintenance has been used to perform both functional contracting (e.g., guardrail repair) and general contracting (e.g., overall maintenance of a designated highway section). Contracts for maintenance can also be based on repair, restoration, or services connected with a single project or provided over a specified period of time. Current practices used for contract development (including the decision to contract), implementation, and administration need to be collected and shared through practical guidelines for use by state highway departments.

The objective of this research was to prepare guidelines for the development, implementation, and administration of maintenance contracts. When formulating the original scope of work, recognition was given to the existence of *NCHRP Synthesis of Highway Practice 125,* "Maintenance Activities Accomplished by Contract." Consequently, this research was designed to extend the state of the art represented by the Synthesis and, then, based on that information, develop guidelines.

Research is complete, and the final report has been published as *NCHRP Report 344,* "Maintenance Contracting." The report contains an assessment of current practices and provides general guidance on contracting for highway maintenance. The state-of-the-art assessment is based on data obtained from 58 highway agencies (42 states, 7 Canadian provinces, 6 counties, 1 city, and 1 regional agency), the U.S. Forest Service, and 29 contractors. The guidelines contain information and direction for deciding when and how to contract for maintenance.

Project 14-9(4) FY '91

Role of Highway Maintenance in Integrated Management Systems

Research Agency:	Cambridge Systematics, Inc.
Principal Invest.:	Michael J. Markow
Effective Date:	April 15, 1991
Completion Date:	July 15, 1993
Funds:	$225,000

Management systems have been developed and modified by units within highway departments since the introduction of the mainframe computer. Most were developed as independent systems within individual units and were not integrated with other transportation data bases. Moreover, these management systems were developed over many years and, because of the ever changing characteristics of computer hardware and software, are incompatible in terms of the efficient and timely flow of information between them. They are also based on various hardware systems from mainframes to PCs, in various configurations from centralized to decentralized management structures. The data structures vary from flat files through hierarchical and relational methods. Improvements in Geographic Information Systems (GIS) for transportation, in recent years, show promise of integrating many of these incompatible data base systems.

Transfer of information among the various transportation data bases would allow a better coordination of maintenance programs with short- and long-term highway improvement programs and, thus, better resource utilizations. The data bases include but are not limited to pavements (PMS), bridges (BMS), equipment (EMS), roadway inventory and condition, design, construction, human resources, materials, finance, accidents, traffic, and safety. Transportation managers also need access to information in the Maintenance Management Information Systems (MMIS).

To exploit the full capabilities of transportation information systems, research is needed to evaluate the effective use of these systems for the purpose of planning, budgeting, scheduling, monitoring, and controlling highway maintenance programs and activities.

The objectives of this project are to design an idealized MMIS based on data available from all transportation information systems and develop a guide to assist state transportation agencies in moving toward implementation. Accomplishment of these objectives will require the following tasks: (1) Conduct a literature search and a survey of state DOTs to determine how maintenance information is generated and used. Identify the state of practice and planned improvements in MMIS and other transportation management systems. (2) Based on the results of Task 1, conduct an in-depth evaluation of a minimum of five DOTs representing the wide range of MMIS currently in existence. Identify and assess the availability of data in transportation management information systems that could be used in the maintenance management decision process. This evaluation should also identify maintenance information needs at all levels that are not currently being met with existing systems; systems components, relationships, and incompatibilities; analytical tools and expert systems; standardization and data exchange issues; location-reference methods; accuracy and precision issues; and timeliness of information. (3) Based on the results of the previous tasks, develop the framework for an idealized MMIS. The framework should include a matrix of information needs, identifying the elements required with regard to the systems seeking and providing the information. In addition, establish criteria to measure benefits arising from

the implementation of the proposed MMIS. The design should allow an incremental evolution from existing systems to the idealized MMIS. (4) Prepare an interim report documenting the research completed in the first three tasks. (5) Complete the design of the idealized MMIS based on the project-panel-approved framework in Task 4. The design should contain sufficient detail to allow for the incremental development from existing MMIS by any state DOT. (6) Identify how the implementation of the proposed MMIS will potentially benefit highway maintenance programs and other department activities. (7) Prepare a final report documenting the research effort. Based on the results of the previous tasks, prepare a management guide to assist transportation agencies in moving toward incremental implementation of the idealized MMIS. The guide must be capable of serving as a stand-alone document.

All work has been completed and the final report will be published in the NCHRP Report series in mid-1994.

Project 14-9(5) FY '91

Impacts of Environmental, Health, and Safety Regulations on Highway Maintenance

Research Agency: Auburn University
Principal Invest.: Dr. A. Ray Tarrer
Effective Date: May 1, 1991
Completion Date: May 31, 1993
Funds: $150,000

The number and complexity of environmental, health, and safety regulations have proliferated in recent years. In order to respond to these regulations, transportation agencies have been required to invest increasingly larger shares of their highway maintenance resources to achieve compliance. These regulations have often been imposed without adequate recognition of the resources, technology advances, or the time required to achieve compliance. In addition, budget constraints have caused maintenance agencies to absorb the cost of compliance by reducing the funds and other resources available for needed maintenance work. Ultimately, deferred maintenance may lead to expensive infrastructure rehabilitation and replacement projects.

Many transportation maintenance operations are facing environmental, health, and safety requirements that have multiple impacts on available resources. Actions taken to achieve compliance may include alteration of operating procedures, modification of existing equipment, purchase of new equipment, selection of new and possibly more costly materials, and implementation of extensive record-keeping procedures. For example, recently adopted federal regulations that are intended to control lead particles in soil and water have significantly increased the costs of removing lead-based paints from existing steel bridges. Several states now claim that it is more cost effective in some instances to remove and replace a steel bridge than it is to remove the lead-based paint. Another example relates to current air quality regulations that limit the use of pavement-marking materials that have highly volatile components. Alternative pavement-marking materials require costly retrofitting of application equipment and often have reduced performance characteristics.

Environmental, health, and safety regulations are promulgated by a number of agencies at the federal, state, and local government levels. These regulations are often issued without full knowledge of the implications on transportation maintenance activities. Conflicts between these regulations and inconsistencies in their interpretation often arise because the highway and regulatory agencies do not effectively communicate on a regular basis.

Research is needed to assist transportation agencies to effectively comply with environmental, health, and safety regulations in maintenance operations. Specific areas where current regulations have significant impact on maintenance operations must be identified, and a framework must be developed for the quantification of costs associated with environmental regulation compliance in order to allow transportation agencies to adequately budget maintenance resources.

The objectives of this research are to identify the technical, operational, and economic impacts of environmental, health, and safety regulations on highway maintenance programs and to provide information for transportation agencies and legislative decision-makers on the costs and consequences of regulatory compliance. The project objectives will require performance of at least the following tasks:

Task 1. Identify and discuss areas where state highway maintenance operations have been significantly impacted by federal, state, and local environmental, health, and safety regulations. The areas that should be considered include air, water, and noise quality; wetlands; material spills and their containment; solid and liquid wastes; herbicides and pesticides; paints; underground fuel tanks; deicing chemicals, solvents, hazardous materials and wastes; and heavy metals.

Task 2. Develop a framework for the quantification of costs related to compliance with environmental, health, and safety regulations as they affect highway maintenance operations.

Task 3. Describe, through the examination of several case studies, examples of the total cost of compliance and/ or noncompliance with existing regulations on highway maintenance operations. These case studies should address environmental issues that have widespread and significant impacts on highway maintenance operations.

Task 4. Describe how funds are typically budgeted and provided at the state and local levels in order to respond to environmental, health, and safety regulation requirements that affect highway maintenance operations.

Task 5. Describe strategies that have been employed by transportation agencies to effectively implement and respond to environmental, health, and safety regulations through such

areas as internal communications, staffing, research, and training.

Task 6. Describe strategies that have been used to enhance coordination and cooperation between transportation agencies and the federal, state, and local environmental, health, and safety regulatory agencies.

The revised final report was received in mid-1993 and a decision is being made on its publication. The report contains an executive summary targeted to legislators and top-level administrators noting problems with environmental and safety regulations and providing suggestions for legislative relief. It also contains a handbook for maintenance operations staff providing recommendations for budgeting and responding to regulations, summarizing pertinent regulations, and providing examples of successful mitigation techniques.

Project 14-9(6) FY '91

Professional Development of Maintenance Engineers and Managers

Research Agency: University of Maryland
Principal Invest.: Dr. Everett C. Carter
Effective Date: February 1, 1991
Completion Date: January 31, 1993
Funds: $174,998

Transportation-maintenance engineers and managers face increasingly complex challenges because of environmental issues, rapidly changing technologies, infrastructure deterioration, and budget and resource constraints. To meet these challenges, maintenance professionals rely upon on-the-job training supplemented by infrequently available courses and workshops. More formal educational programs and opportunities are needed to assist today's maintenance professional meet the demands.

Educational opportunities must also be created or identified to familiarize, attract, and prepare people to pursue professional careers in maintenance. There are few educational opportunities available to the aspiring maintenance professional. As the complexities of highway maintenance and the magnitude of the problems continue to increase, the development of highly skilled and trained professionals will increase in importance.

The ultimate goal is to enhance the profession of transportation maintenance engineering and management. As the emphasis shifts away from new construction to maintaining and rehabilitating the infrastructure, properly trained professionals are needed to make more efficient and effective use of limited resources.

As a first step in correcting this neglected area of civil and transportation engineering, an educational framework must be designed to encourage and guide universities, the professional community, and others in implementing programs to assist both existing and aspiring maintenance professionals. The framework must include model curricula for the transportation maintenance professional as well as guidance for implementation.

The objective of this research is to design an educational framework and an implementation plan for the professional development and enhancement of highway-maintenance engineers and managers. Emphasis will be placed on programs and courses for maintenance professionals who are, or will be, serving within highway and street departments of state and local governments. The framework should address, but not be limited to, engineering, personnel, and resource management. To accomplish this objective, the following tasks must be performed as a minimum.

Task 1. Identify and describe common responsibilities and knowledge requirements for professionals involved in highway-maintenance engineering and management at state and local levels.

Task 2. On the basis of the results from Task 1, develop a classification structure of education and training needs for highway-maintenance engineering and management professionals. This classification structure should include, but not be limited to, the following.

- *Maintenance types* (e.g., preventive, routine, repairs, rehabilitation, disaster preparedness and response, and traffic services).
- *Functional areas* (e.g., roadsides, pavements, structures, and traffic control).
- *Engineering and management issues* (e.g., personnel, materials, equipment, environmental concerns, contract administration, financial matters, legal issues, public and employee safety, maintenance management systems, public relations, design and execution of maintenance operations, productivity, and quality assessment, assurance, and control).

Task 3. On the basis of the results of Task 2, develop the educational framework for enhancing the education of highway-maintenance engineering and management professionals. This framework should include, but not be limited to, alternatives consisting of new or existing programs that are fully described and address the following areas:

- *Curricula and training programs* (e.g., university/college programs, and continuing education programs).
- *Training delivery methods* (e.g., classroom instruction, seminars, workshops, self-paced studies, video tapes, textbooks, and handbooks).
- *Implementation mechanisms* (e.g., national institute, professional societies, and agency training programs).
- *Evaluation and feedback mechanisms* (e.g., committee reviews and student evaluations).

Task 4. On the basis of the framework developed in Task 3, evaluate and recommend implementation plans and strategies. The potential for and interest in various strategies shall be assessed by approaching individuals or organizations that

would have the ultimate responsibility for successful implementation.

Task 5. Prepare a final report on the total research effort.

All work has been completed and the final report will be published as NCHRP Report 360, "Professional Development of Maintnenace Engineers and Managers," in early 1994.

Project 14-10 FY '89

Improvements in Data Acquisition Technology for Maintenance Management Systems

Research Agency: The Urban Institute
Principal Invest.: William A. Hyman
Effective Date: May 29, 1989
Completion Date: March 31, 1993
Funds: $300,000 ($100,000—Phase I and $200,000—Phase II)

Initial project work (Phase I) has resulted in the identification of an assortment of new technologies which have the potential of greatly improving the effectiveness and efficiency of various highway maintenance activities where the collection, retention, or use of data is required. Recommendations have been made on the application of these technologies to six generalized scenarios: (a) Crew data collection, (b) Inventory Management and Control, (c) Roadway Feature Inventory Updating, (d) Inputs to Short Run Scheduling, (e) Bridge Inspection and Maintenance, and (f) Heavy Snow Removal Equipment Monitoring. Given the opportunity for additional work under this project, the NCHRP has decided that pursuing further developments under scenarios a, c, and d would allow the testing and demonstration of the greatest number of new technologies to further achieve the project objective of improving the acquisition, recording, field verification, transmission, and receipt of field-related data for maintenance management systems. The focus of the additional work (Phase II) will be aimed specifically at those activities performed by first-level maintenance supervisors (crew chief). To accomplish this second phase of work, the following tasks will be required as a minimum:

Task 1 Preliminary Demonstration Design. Develop and describe the requirements of the demonstrations to include as many technologies as appropriate.

Task 2 Arrangements with Cooperating States. Identify at least 2 state departments of transportation willing to help sponsor the demonstrations. Efforts shall be made to gain assistance in providing realistic conditions including direct 2-way linkage, where possible, with the states' maintenance management systems.

Task 3 Preparatory Studies. Evaluate site conditions to include the working environment and personnel. Focus groups and hands-on, staged demonstrations are recommended.

Task 4 Hardware and Software Acquisition. Develop or obtain all necessary hardware and software necessary for a successful demonstration.

Task 5 Final Demonstration Design. Develop the precise procedures for conducting the demonstrations at the host states. The design shall include the measures by which the demonstrations will be judged, for example, cost effectiveness, worker acceptance, quality of data collected, and increased productivity. Submit for approval to the host states and the NCHRP.

Task 6 Demonstrations. Upon approval, conduct demonstrations at the host states. Video taping selected operations should be considered.

Task 7 Final Report. Document the development and results of the demonstrations, the conclusions, and recommendations. The recommendations shall provide instructions to states on the application and implementation of the technologies.

Phase I is complete and the final report published as NCHRP Report 334, "Improvements in Data Acquisition Technology for Maintenance Management Systems." The Phase I final report contains generic descriptions of available technologies and describes potential applications of each. Preliminary system designs are also presented for six maintenance activity scenarios.

All work has been completed and the final report has been published as NCHRP Report 361, "Field Demonstrations of Advanced Data Acquisition Technology for Maintenance Management."

Project 14-11 FY '89

Effective Motivation of Highway Maintenance Personnel

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. H. Randolph Thomas
Effective Date: June 1, 1989
Completion Date: December 31, 1992
Funds: $200,000

The objective of this research was to develop a training program, with associated materials, for highway maintenance managers and supervisors at all levels which will enable them to effectively motivate themselves and their subordinates. The goal of this program was to provide managers and supervisors with the skills necessary to assess personal and organizational needs, and to identify suitable motivational tools that can enhance employee satisfaction, work quality, efficiency, and other aspects of performance.

Accomplishment of this objective required at least the following tasks:

Task 1. Use an extensive literature search, interviews with knowledgeable individuals, and other appropriate survey techniques to identify, from a broad spectrum of private

techniques to identify, from a broad spectrum of private and public organizations, those personal and organizational attributes and needs that are associated with employee motivation. Emphasis should be placed on information relevant to a state highway agency environment.

Task 2. Based on the results from Task 1, develop a practical method that can be used at all levels from the first-level supervisor to the top maintenance manager to recognize and assess those personal and organizational attributes and needs that can affect employee behavior and performance. This method should be applicable to highway maintenance organizations at the state, city, or county level.

Task 3. Identify and develop motivational tools that can be used in a highway agency environment to address personal and organizational needs and, thereby, produce desirable changes. Document the conditions under which the motivational tools should and should not be used, and the expected end results. In addition, identify and evaluate available training materials, visual aids and resource materials that illustrate the application of these motivational tools.

Task 4. Develop a comprehensive training program to instruct maintenance managers and supervisors in the use of the method developed in Task 2, and the motivational tools identified or developed in Task 3. In addition, develop criteria for evaluating the effectiveness of the training program on a short-term and long-term basis. At a minimum, this task should produce visual aids, testing materials, program evaluation criteria, an instructor's handbook properly referenced with the visual aids, and a handbook for maintenance managers and supervisors.

Task 5. Prepare an interim report documenting the research completed in Tasks 1 through 4. Submit the interim report for review by the NCHRP project panel. Soon after distribution of the interim report, a meeting between the research team and the NCHRP project panel will be held for the purpose of providing panel members with a "walk through" of the training program and the opportunity to discuss the contents of the interim report. NCHRP approval of the interim report will be required before proceeding with Task 6.

Task 6. Conduct a pilot presentation of the training program in a highway maintenance organization to be selected by NCHRP. Using the short-term evaluation criteria developed in Task 4, evaluate the pilot effort and adjust the training program materials, as necessary, to maximize their effectiveness.

Task 7. Prepare a final report documenting the research, including the instructor's handbook, maintenance manager's and supervisor's handbook, and testing materials. It should also include a discussion on the expected benefits to an agency using the training program. Ten reproducible copies of all visual aids will also be required.

The final report and course materials have been reviewed and are available on request. A continuation project will soon be initiated to enhance and supplement the training

AREA 15: GENERAL DESIGN

Project 15-10 FY '85

Development of a Design/Graphics Interface System

Research Agency: C.W. Beilfuss & Associates, Inc.
Principal Invest.: Charles W. Beilfuss
Roy R. Guess
Effective Date: August 1, 1985
Completion Date: November 30, 1988
Funds: $500,000

More and more state departments of transportation are relying on computer-aided design and drafting (CADD) systems to help them prepare and produce their roadway designs. The procurement and implementation of such systems do not usually occur at one time throughout all departments. Consequently, state DOTs may acquire a variety of systems over time, or they may wish to continue to take advantage of new technologies as they evolve. State DOTs also contract design work to consultants who may or may not have compatible systems. This array of possible situations highlights the potential problem of exchanging graphic and design data among various systems. Inadequate capability for such exchanges hinders productivity, limits competition, and inhibits the advantageous use of new developments in hardware and software.

The primary objective of this research was to design a standard file for the exchange of computerized roadway design and graphics data. A standard file, if adopted and maintained, would have the potential of facilitating the transfer of data between existing, but different, systems and for providing a target for future software program developments. Based on a thorough investigation of DOT needs, systems used, and interchange formats, a specification was defined for a standard file format, the Common Data Interchange File (CDIF), that could accommodate interrelated roadway design and graphics data. Prototype software for data-interchange processes was also developed for the more commonly used state DOT systems to demonstrate the utility of the interface.

Research is complete and the main text of the final report has been published as NCHRP Report 326, "Development of a Roadway Design/Graphics Interface System." The appendixes to the agency's final report were not published, but copies of that report, entitled "Development of a Design/Graphic Interface System—Appendixes A–E," were transmitted to all state DOTs addressed specifically to the membership of the AASHTO Administrative Subcommittee on Information Systems. Others may obtain copies on loan or for purchase. The appendixes are titled as follows: Appendix

A, Guidelines for Entry of Data to be Transferred; Appendix B, Common Data Interchange File Specification; Appendix C, Information for DIP Usage; Appendix D, Programmer Information for DIP Enhancement/New Development; and Appendix E, Test Data.

The research agency also demonstrated, to a limited extent, the actual exchange of information. The computer programs employed for this purpose are available for use and further development. All of the software was developed in FORTRAN for a DEC VAX environment. The descriptions are written using DEC VAX terminology and descriptive notations. The FORTRAN source code, executables, and test data are available for DEC VAX computer systems on a single magnetic tape (9 track, 1600 BPI, 1200 foot reel).

Project 15-11 FY '87

Computer-Aided Analysis of Highway Encroachments on Mobile Boundary Streams

Research Agency: Simons and Associates, Inc.
Principal Invest.: D. B. Simons and A. Molinas
Effective Date: July 1, 1987
Completion Date: March 31, 1990
Funds: $249,360

More than 85 percent of the 571,000 bridges in the National Bridge Inventory are constructed over waterways that are subject to various degrees of scour and lateral stream migration (erosion) during floods. In addition, many miles of highways are built along and encroach on streams. Although there are no accurate statistics, a great deal of damage to bridges and highways is caused each year by degradation, aggradation, and scour. Conversely, in an attempt to avoid these problems, some highways and bridges may be designed too conservatively. For example, some bridge foundations may be deeper than necessary, which increases costs.

Engineers realize that streams can degrade, aggrade, and change location within flood plains and that the actual construction of a bridge or highway may initiate additional morphological changes in the behavior of a stream. However, existing design procedures for highway structures assume for the most part that streams have fixed boundaries. Although state-of-the-art analyses are available for the mobile boundary stream condition, they are seldom used, and if assessments are accomplished at all, they are based primarily on the designer's judgment and experience.

The principal reason for the current situation is that available analytical procedures are difficult to use and have not been adapted to highway applications. After a thorough review of existing computer models to aid in analyzing mobile boundary streams, a conclusion was reached, during a session of the Transportation Research Board's Second Bridge Engineering Conference at Minneapolis in September 1984, that none of the existing computer models would be totally suitable to aid either in the design of highway bridges or in determining the effects of longitudinal encroachments. For example, some existing models apply only to long stream reaches; others are not detailed enough for bridge openings and do not predict lateral erosion of streams; and many are not user-friendly.

The objective of this research project was to develop and test a practical computer model that was based on sound physical principles of flow and sediment interaction and was designed to estimate water-surface profiles, aggradation, degradation, scour, and bank widening due to bridges and longitudinal encroachments located on mobile boundary streams. The estimates were to be used to aid in the design of highway crossings or other encroachments of streams.

This research project is complete; however, a continuation phase has been initiated—see write-up for Project 15-11A, "BRI-STARS Maintenance Support and Enhancement." Documentation for this portion of the research has been provided to NCHRP sponsors. This documentation included a User's Guide for BRI-STARS (Bridge Stream Tube Model for Alluvial River Simulation), the final software product for this phase. On reading the documentation and if interested, sponsors could have requested the software from the NCHRP and be given instructions on access to the electronic bulletin board system established under Project 15-11A.

Project 15-11A FY '87

BRI-STARS Maintenance Support and Enhancement

Research Agency: Hydrau-Tech, Inc.
Principal Invest.: Dr. Albert Molinas
Effective Date: June 1, 1991
Completion Date: November 30, 1993
Funds: $99,827

In response to the original Project 15-11 objective, which was "to develop and test a practical computer model that is based on sound physical principles of flow and sediment interaction and is designed to estimate water-surface profiles, aggradation, degradation, scour, and bank widening due to bridges and longitudinal encroachments located on mobile boundary streams," BRI-STARS (Bridge Stream Tube Model for Alluvial River Simulation) and an expert type system for stream classification were created. The NCHRP Project Panel concluded that Project 15-11 was successful, but that further work was necessary to ensure fully operational computer software packages in realistic work environments and to provide desired enhancements. Presently, the product of the initial effort remains in the experimental stage; copies of any software will be released to only the sponsors of the NCHRP and other selected government agencies. Specifically, the NCHRP has defined four areas: (a) enhancements, (b) maintenance support, (c) a pilot workshop, and

(d) final documentation. The requirements of the four areas are detailed below.

Task 1 Enhancements. The following list of enhancements is prioritized by groups and within groups as a guide for allocating costs and the overall effort. The first priority items are a definite requirement of the requested work. The second priority items are highly desirable. The third priority items are provided in the event that there are remaining funds after the accomplishment of priorities 1 and 2.

First Priority

1. Add the following:
   A. Pier scour, HEC-18 updates
   B. Contraction scour option using Larson's equations (for comparison purposes)
   C. Abutment scour from HEC-18
2. Complete Expert System (Stream Classification) linkage to BRI-STARS to help guide the selection of:
   A. Range of appropriate N values
   B. Number of stream tubes
   C. Sediment equations
   D. Channel widening alternative
   E. Armoring possibility and active layer determinations
   F. Appropriate time step
3. Improve calibration guidelines
4. Make WSPRO, BRI-STARS, and HEC-2 more compatible

Second Priority

1. Provide input of N-values by subareas
2. Accommodate changes in bed material by subarea and in overbank areas
3. Accommodate variable particle size distribution by depth

Third Priority

1. Include more points and cross-sections
2. Include set-back abutments
3. Include velocity distribution (Bends)
4. Add DOS 4.0 (Windows)
5. Add mass wasting (bank failures)
6. Provide better integration of WSPRO for design
7. Include stream classification pictures
8. Provide HYDRAIN compatibility
9. Include estuaries

Task 2 Maintenance Support. The proposer will establish an electronic bulletin board system on which to receive comments and questions from users of BRI-STARS. The NCHRP will furnish each state DOT, other selected governmental agencies, with a copy of the BRI-STARS documentation. They will be notified, that if interested in experimenting with the BRI-STARS software, to contact the proposer through the electronic bulletin board. A copy of BRI-STARS would then be mailed with all future communications being accomplished through the bulletin board system. The proposer will be responsible for responding to all inquiries and providing any modifications (of a minor nature) directly to the users. In general, the users and the proposer will have the additional opportunity to share experiences and examples, and the proposer shall encourage this. Input from this activity will be used to finalize BRI-STARS and all related systems.

Task 3 Pilot Workshop. Conduct a workshop, for 20 to 30 people, of approximately 3 days duration in the eighth or ninth month of the proposed contract period. The primary purpose of the workshop will be training for all BRI-STARS related products. User input through the bulletin board system should be used to guide the type and level of instruction. A detailed course outline shall be submitted to the NCHRP 3 months prior to the workshop for review and acceptance. A means to critique the course for the purpose of suggesting improvements in future versions should be provided.

Task 4 Final Documentation. Prepare the final report to include documentation of the research effort, the final version of all software and user's manual (suitable for general distribution), and workshop material including a modified suggested course outline.

Research is complete; the agency's final documentation is under review. First and second priority items noted above were accomplished.

Project 15-12 FY '88

Roadway Widths for Low Traffic Volume Roads

Research Agency:	Jack E. Leisch & Associates
Principal Invest.:	Charles V. Zegeer and Timothy R. Neuman
Effective Date:	May 1, 1989
Completion Date:	October 31, 1993
Funds:	$250,000

The objectives of this research are to develop an engineering analysis procedure for determining roadway width for the construction and reconstruction of low volume roadways (less than 2,000 ADT) and, based on this analysis, to develop "minimum width of traveled way and shoulder" recommendations for consideration by the Geometric Design Task Force of the AASHTO Highway Subcommittee on Design for inclusion in future editions of the *Greenbook.*

This project will consist of at least six tasks as follows:

Task 1. Conduct a critical review of all pertinent literature dealing with safety, operations, and geometrics of low volume roads as they pertain to and impact on roadway width.

Task 2. Based on the results of Task 1, develop a data collection and analysis plan for acquiring the additional data needed to accomplish the project objectives. Variables to be included in this analysis shall include but not be limited to traffic volume, vehicle speed, percent trucks, geometrics, roadway functional classification (arterial, collector, and local), level of service (Reference: *Greenbook,* Table II-6, p. 96), traffic accident data, and associated costs (i.e., traffic accident and roadway construction, renovation, and mainte-

nance). Prepare and distribute to the NCHRP Project Panel an interim report describing the results of this task.

Task 3. Implement the plan developed in Task 2.

Task 4. Based on the analysis of information obtained in previous tasks, develop an engineering analysis procedure for determining roadway width for roadways with an ADT of less than 2,000. This procedure shall incorporate an optimization of the costs and safety benefits for various roadway widths. Using the engineering analysis procedure, develop recommended roadway widths related to site conditions. It is anticipated that the traffic volume variable will require a minimum of three categories below 2,000 ADT. Prepare and distribute to the NCHRP Project Panel an interim report describing the results of this task.

Task 5. Apply the recommended roadway widths developed in Task 4 and the current width criteria found in the *Greenbook* to low traffic volume roadways constructed or reconstructed in three states and two counties during the last 5 years. The states and counties will be selected by NCHRP. Based on this analysis, determine the number of additional miles of roadway that could have been constructed or reconstructed in these 5 jurisdictions using the recommended roadway widths. In addition, determine the associated safety impact of applying the recommended roadway widths.

Task 6. Prepare a final report documenting the results of Task 1 through Task 5.

The project has been completed and efforts are underway to publish the report.

Project 15-13 FY '90

Long-Term Performance of Geosynthetics in Drainage Applications

Research Agency:	Geosynthetic Research Institute of Drexel University
Principal Invest.:	Dr. Robert M. Koerner
Effective Date:	April 1, 1990
Completion Date:	March 31, 1993
Funds:	$455,240

The use of geosynthetics in drainage-related applications has increased rapidly in the past 10 to 15 years. Geosynthetics include geotextiles, geotextile/aggregate, geotextile/pipe, and prefabricated drainage systems. Applications include, but are not limited to, pavement edge drains, underdrains, slope drains, drainage behind retaining walls, french drains, and interceptor drains. Wick drains are specifically excluded from the scope of this research. In general, geosynthetics are used rather than graded filters because of their lower initial cost and ease of construction.

Although there is information on the advantages and design of geosynthetics, there is little quantitative information regarding long-term performance over the design life of the facility. The initial cost advantage of geosynthetics can be negated if they do not have a sufficiently long life and have to be replaced prematurely. Inadequate performance of geosynthetics may lead to failures of pavements, slopes, or retaining walls.

Questions about drainage performance of geosynthetics can be divided into four areas: (1) appropriateness of the application, (2) design methodology, (3) relationship of design properties to field performance, and (4) installation.

The objectives of this project are: (1) to document the design and performance of existing installations of geosynthetics in drainage applications, including the appropriateness of use, construction techniques and related problems, failure mechanisms and their consequences, and factors affecting long-term performance; and (2) to recommend material properties, test methods, specification values, and design and construction criteria.

The research will include the following tasks: (1) Review relevant literature, research findings, design methods, and performance data on geosynthetic drainage systems to assess the state of the art. This review should not be limited to highway or transportation-related projects, but should include applications in areas such as agriculture and buildings. (2) Conduct a survey of state highway agencies and other appropriate organizations to develop a list of candidate sites for in-service performance evaluation of geosynthetic drainage systems. This candidate list should include sites with failures and successes, sites with various soil conditions and geosynthetics applications, and sites that have been used by agencies for experimental purposes. This survey should also include any other information pertinent to this research. (3) Submit an interim report within 6 months after initiation of the research. The interim report shall include a summary of the data collected in Tasks 1 and 2, and a detailed plan for a proposed field and laboratory investigation program to be conducted in Task 4. Sites shall be selected to obtain a reasonable balance between sites with documented successes and failures, and a variety of soil conditions, with particular emphasis on encompassing the full range of geosynthetic applications. (4) For selected sites, review design and construction records and conduct a field and laboratory investigation program to document: (a) the performance of the drainage system and compare it with design expectations and product claims; (b) the presence or absence of any system or component problems such as physical, chemical, or biological clogging, material deterioration, physical damage, construction failures, inadequate hydraulic capacity, or excessive core compression; (c) the causes and consequences of any problems noted in b; and (d) any other items that would be useful in preparing procedures and specifications, for design and construction or in planning further research in this field. (5) Analyze and compare the field and laboratory test results with the design and construction procedures and specification values based on the results of this investigation. Recommended test procedures should be in a format suitable for adoption by AASHTO or ASTM. (6) Prepare a final report documenting the research efforts and the research findings.

The preliminary draft final report has been approved by the project committee. The Principal Investigator will complete the revisions and submit the final report.

Project 15-14(1) FY '92

Intersection Sight Distance

Research Agency: Midwest Research Institute
Principal Invest.: Douglas W. Harwood
Effective Date: June 1, 1992
Completion Date: November 30, 1994
Funds: $350,000

Current procedures provided by AASHTO's *A Policy on Geometric Design of Highways and Streets,* 1990 (the "Green Book"), are intended to provide adequate sight distance at intersections to promote safe and efficient traffic operations. These procedures are applied to a variety of intersection traffic controls, including no control, stop control, and signal control. The basic intersection sight distance (ISD) models for these situations were formulated in 1940. Over the past 50 years, the model parameters have been modified to account for changes in the vehicle-driver-roadway system.

Recently, questions have been raised about the validity of the models, as well as the appropriateness of certain parameter values used to calculate ISD. In addition, recent research has recommended possible alternative models, one of which includes the consideration of gap acceptance.

It has been the experience of highway engineers applying the current AASHTO models that the ISD required for Cases IIIB and IIIC may be excessive. There is also concern that Case I ISD values may be unconservative. Situations, such as a vehicle turning left off the major roadway, moreover, are not addressed. It is possible that these deficiencies may be contributing to the misuse of ISD criteria by both state and local jurisdictions. Considering the high construction costs and uncertain safety benefits associated with long intersection sight distances, state highway officials have concluded that a substantial research effort is needed to re-evaluate available information, collect additional data, and recommend improvements to current practice, if required.

The objective of this research is to evaluate current AASHTO methodology for Cases I, II, III, and IV intersection sight distance and, where appropriate, recommend new or revised models. Recommended design procedures will be developed for specific applications based on a review of current and alternative practices, updated representative vehicle-performance characteristics, roadway characteristics, and driver-behavior data. Issues such as the function of the roadway facility, cost- and safety-effectiveness of the design, and ease of applying the sight distance models shall be taken into account.

To accomplish this objective, the following tasks will be conducted:

Phase I

Task 1. Conduct a review of pertinent domestic and foreign literature, research, and practices on, as a minimum, the following topics: (a) driver behavior, including behavior of older drivers (gap acceptance characteristics, threshold limits for driver decisions, perception-reaction times, time required for crossing/turning maneuvers, object recognition, and case III driver position); (b) vehicle (size, i.e., passenger car vs. truck, acceleration/deceleration characteristics, and day and night conspicuity); (c) intersections (geometry, traffic control, and day and night visibility); (d) relationship between ISD and safety; (e) alternative ISD methodologies including those considered or adopted by other countries, under development by researchers, or suggested by the literature; and (f) tort-liability exposure of highway agencies related to ISD.

Task 2. Evaluate the practices and procedures of intersection design identified in Task 1. The evaluation should address, as a minimum, (a) each of the four AASHTO cases and vehicles turning left off the major roadway, (b) functional class of the roadway, (c) speeds on the roadway, (d) roadway cross section and geometrics, and (e) vehicle type. Perform a critical analysis of the AASHTO models and other promising ISD models, including the parameters required in each model. The alternative models may be either suggested in the literature or developed in the course of the research. The advantages and disadvantages of each model should be thoroughly documented, including model practicality and complexity. Any deficiencies in the available data needed to accurately assess the model's impact, validity, or practicality should be carefully documented. Finally, a fully supported recommendation, taking into account cost-effectiveness, shall be made concerning the retention of the current AASHTO ISD models or the potential implementation of refined AASHTO or alternative ISD models.

Task 3. Within 10 months after the start of the project, prepare and submit an interim report consisting of two parts. The first part will document the results of Tasks 1 and 2. The second part will be a detailed plan for conducting the Phase II portion of the project. The plan shall describe the rationale, methods, required data, data collection, schedule, budget, and special facilities, equipment, or arrangements required to perform Tasks 4, 5, and 6. The purpose of these tasks is to validate and refine the models recommended in Task 2. Immediately following review by the project panel, the research agency will be required to make a presentation to the project panel in Washington, D.C.

Phase II

Task 4. Collect data and, where appropriate, conduct field studies to implement the plan recommended in Task 3 and approved by the NCHRP.

Task 5. Based on the preceding tasks, refine and validate the recommended ISD models and determine the credibility, ease of use, and cost/benefit impact of applying the recom-

mended ISD models. As a minimum, the validation shall include: (a) a sensitivity analysis of the parameters used in the recommended models, (b) a comparison of the ISD values obtained from the new or revised models with the existing AASHTO ISD models if necessary, (c) an assessment of the impacts in terms of costs and benefits, and (d) an assessment of the impact on tort liability of the recommended ISD models on new and existing intersections. Revise the models, as needed, and develop final recommendations on the basis of the findings of this task.

Task 6. Prepare a final report. The report will cover the entire project. All data necessary to use the models recommended in Task 5 will be included in the report, and, if appropriate, provided on computer disks.

Research on Tasks 1 through 3 has been completed, and the Phase I report has been reviewed and approved by the project panel. Work on Task 4 is proceeding on schedule.

Project 15-14(2) FY '92

Median Intersection Design

Research Agency:	Midwest Research Institute
Principal Invest.:	Douglas W. Harwood
Effective Date:	December 1, 1992
Completion Date:	November 30, 1994
Funds:	$350,000

Operational design of median widths and geometric configurations at intersections to meet the needs of rural and suburban traffic continues to be a concern. As noted in AASHTO's *Policy on Geometric Design of Highways and Streets,* the width of medians at intersections on highways with partial or no access control is critical to their operation and safety.

Median-width research efforts have, for the most part, addressed freeway operations only. These efforts have provided a significant amount of information on cross-section design and optimum width. However, little or no research has been directed toward developing guidelines for median widths at intersections with partial or no access control.

Median width on these facilities may pose operational problems in the vicinity of intersections for (1) left-turning traffic from the main roadway and (2) crossing or left-turning traffic from crossroads. These problems may be created or compounded by other factors, such as the expanse of pavement area, inadequate storage for turning or crossing vehicles, restricted sight distance at the intersection approaches, and violations of driver expectations for traffic movements (for example, drivers tend to become confused about intended operational characteristics of the multiple intersections encountered).

Currently, the focus of many transportation agencies is on the construction or reconstruction of multilane facilities having partial or no access control. Because current design policy does not adequately address median widths or intersection treatments on these types of facilities, guidance is urgently needed.

The objectives of this research are to develop and recommend median-width parameters and design criteria for intersections on rural and suburban highways with partial or no access control. Guidelines to be developed for new and reconstructed facilities should consider at least the following: (1) Safety, (2) Traffic Operations, (3) Traffic Volumes, (4) Type of Traffic Control, (5) Design Speed of the Facility, and (6) Traffic Characteristics. Secondary issues that may be considered include intersection configuration and intersection spacing.

Accomplishment of these objectives will require at least the following tasks: PHASE I—(1) Conduct a review of domestic and foreign findings and other research literature pertaining to median width at intersections on rural and suburban facilities having partial or no access control. (2) Review and evaluate existing practices and procedures relating to median width at intersections, with specific emphasis on the considerations enumerated in the objectives, and other factors as appropriate. Identify potential study sites, including those known to operate safely and efficiently as well as those known to have safety and/or operational problems, and cite any case histories available. (3) Based on the information from Tasks 1 and 2, develop preliminary guidelines for both median-width parameters and design criteria for intersections on rural and suburban highways. (4) Within 6 months after the start of the project, prepare and submit an interim report consisting of two parts. The first part shall document the findings of Tasks 1 and 2 contain the preliminary guidelines developed in Task 3. This report should also indicate any gaps in available data. The second part will be a detailed plan for conducting the Phase II portion of the project. The plan shall describe the rationale, methods, required data, field-study plan, data collection, schedule, budget, and special facilities, equipment, or arrangements required to perform Tasks 5, 6, and 7. The purpose of these tasks is to validate and refine the preliminary guidelines. Work on Tasks 5, 6, and 7 will not begin until authorized by NCHRP.

PHASE II—(5) Collect existing data and, where appropriate, conduct field studies to implement the plan recommended in Task 4 and approved by the NCHRP. (6) Based on the information obtained in the preceding tasks, refine and recommend guidelines for median-width parameters and design criteria for intersections on rural and suburban highways with partial or no access control. Recommended guidelines shall be prepared in a format suitable for adoption by AASHTO. (7) Prepare and submit a final report documenting the entire research effort.

Research on Tables 1 through 4 has been completed, and the Phase I interim report has been reviewed and approved by the project panel. Work on Task 5 is proceeding on schedule.

AREA 16: ROADSIDE DEVELOPMENT

(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)

AREA 17: SAFETY

Project 17-6A FY '80 and FY '83

Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones (Phase II)

Research Agency: Transportation Research Corp.
Principal Invest.: Fred R. Hanscom
Effective Date: October 15, 1984
Completion Date: May 16, 1990
Funds: $252,277

The objective of this project was to develop guidelines for warning systems on service vehicles and for traffic control in short-term, intermittent moving, and continuously moving work zones. In addition to considering the basic traffic and safety requirements, the guidelines were to also place emphasis on the operational efficiency and cost-effectiveness of each treatment.

This research consisted of two phases. Phase I determined the state of the art through a literature review and a review of current practice. Existing literature was reviewed to identify currently recommended standards, actual practice, and potential improvements. The MUTCD, the FHWA utilities handbook, ITE publications, SAE Handbook, representative state and local manuals, utilities operating practices, and research reports related to vehicle signal lighting and traffic control systems were reviewed. Selected organizations were contacted to obtain more detailed information on the most promising techniques, problems with current practice, and the feasibility and desirability of developing standards.

Typical situations were identified for which service vehicle warning and traffic control systems are needed, and those situations having similar traffic control requirements were combined to reduce the number of alternative treatments to be developed. Short-term, intermittent moving, and continuous moving activities were included. Some of the variables considered included: type of facility; roadway width, number of lanes, shoulder characteristics; urban or rural; traffic volume and speed; physical sight restriction; adverse visibility; activity period (e.g., day or night, peak or off-peak); duration of activity; length of work zones; extent of lane encroachment; lane blockage; and speed of operation.

Service vehicle warning and traffic control systems were developed for each work-type situation. For signal lighting, consideration was given to the effects of color, flash characteristics, number, size, and intensity, as well as the environment in which the vehicle is operating. Other vehicle warning devices such as arrow boards, flags, and vehicle paint schemes were also considered. The traffic control systems include the use, as appropriate, of flagmen, vehicles (e.g., barrier, shadow), and traffic control devices (e.g., signs, channelizing devices, arrow panels). Spacing and size of devices, as well as the placement and number of all elements, are included. In development of the alternatives, consideration was given to the information needs of the motorist, equipment availability, characteristics of service vehicles, cost-effectiveness, portability, traffic operations, and motorist and worker safety (including the added hazard due to the placement and removal of devices).

In Phase II, indoor laboratory studies were conducted to evaluate and optimize the vehicle warning and traffic control systems. Closed field studies were conducted in Maryland to further test the most promising systems. Field tests were conducted in early 1986, under actual highway conditions, using real or simulated work activities, in New York and Louisiana as a final validation of each system.

A final report and an operations guide were prepared describing recommended vehicle warning and traffic control systems developed under this project. This guide is designed to facilitate direct incorporation into state and local manuals used by service personnel in short-term and moving work zones.

Research has been completed, and the final report has been published as NCHRP Report 337.

Project 17-7 FY '86

Guidelines for Converting STOP to YIELD Control at Intersections

Research Agency: Bellomo-McGee, Inc.
Principal Invest.: Dr. Hugh W. McGee
Effective Date: December 16, 1985
Completion Date: May 15, 1989
Funds: $200,000

Studies of low-volume intersections have concluded that control type has no appreciable effect on accident experience. These studies indicate YIELD control is more economical than STOP control because of the reduced delay and road user costs. For higher traffic volume intersections, however, insufficient accident data have been collected to demonstrate the relative safety of STOP versus YIELD control.

The objectives of this research were (1) to determine the accident experience when STOP-controlled intersections are converted to YIELD control, and (2) to develop guidelines for converting STOP control to YIELD control.

The research has been completed, and the final report has been published as NCHRP Report 320, "Guidelines for Converting STOP to YIELD Control at Intersections."

Project 17-8 FY '88

Traffic Barrier and Control Treatments for Restricted Work Zones

Research Agency: Texas A&M Research Foundation
Principal Invest.: Dr. Hayes E. Ross, Jr.
Effective Date: June 1, 1988
Completion Date: June 30, 1993
Funds: $450,000

Many construction projects require the use of traffic barriers to adequately protect the motoring public and construction workers. Geometric and operational restrictions in these work zones frequently preclude the use of the same design standards for these barriers and terminals that normally apply to permanent systems.

One common example involves two-lane, two-way bridges where one-half of the bridge is repaired while maintaining alternating one-way traffic in the remaining lane (usually with temporary traffic control signals). The most common method of traffic control is to install a concrete barrier on the bridge approaches and across the bridge to protect the motorists and workers. While this practice normally provides an acceptable measure of safety for motorists and workers, problems occur when an intersecting highway or driveway that cannot be closed exists near the end of the bridge. In this example, and in other restricted situations, there is often inadequate room to install either the barrier runout at the specified flare rate, an impact attenuator, or other terminal treatments meeting the performance standards for permanent barrier systems.

The objective of this research was to develop improved end treatments for temporary traffic barriers, traffic control plans, and user guidelines for restricted work-zone situations. The following tasks were undertaken:

Phase I

Task 1—Identify types of existing work-zone situations where standard barrier terminal treatments and traffic control plans cannot be installed because of restricted conditions. Examples include bridge ends near an adjacent intersecting street, temporary traffic barriers with roadway/driveway openings, end treatments for barriers on narrow medians, and locations having restricted space for barrier deflection. Selected highway agencies, manufacturers, and other organizations are to be surveyed to determine common problem situations and current treatments.

Task 2—Classify the specific situations identified in Task 1 into groups having similar characteristics. Factors that should be considered include traffic parameters, site features (highway geometrics, terrain), and anticipated frequency of the problem situations.

Task 3—Develop conceptual designs for barrier terminal and traffic control treatments for the groups identified in Task 2. Factors to consider include: design vehicle, approach speed, barrier flare rate, safety, and roadway geometrics. Sloped terminals for concrete barriers under low approach speed conditions will be included as one of the end treatments.

Task 4—Evaluate the proposed treatments for typical situations. Evaluation criteria include safety, traffic capacity, user delay, costs, and ease of implementation.

Task 5—Prepare a report on the findings of the above tasks. This report will contain a detailed work plan for Phase II, including recommendations for the development and evaluation of the proposed barrier terminal treatments through analysis and crash tests.

Phase II

Task 6—Develop detailed designs for barrier terminal treatments.

Task 7—Evaluate the terminal treatments developed in Task 6 through full-scale crash tests.

Task 8—Develop a user's manual including detailed design drawings for recommended barrier terminal treatments and special traffic control plans, and guidelines for their use. This manual will be in sufficient detail and in a format suitable for consideration by AASHTO for incorporation into its design criteria.

Task 9—Prepare final research report.

Phase III

Task 10—Prepare video tape describing the problem and the solutions developed in the research.

The Final Report will be published as *NCHRP Report 358*. The videotape has been completed and is available on a loan basis.

Project 17-9 FY '92

Effects of Highway Standards on Safety

Research Agency:	Bellomo-McGee, Inc.
Principal Invest.:	Dr. Hugh McGee
Effective Date:	February 1, 1992
Completion Date:	May 31, 1994
Funds:	$200,000

Design standards are applied by highway agencies to assure optimal operational and safety performance based on the anticipated use of roads in their system. Ideally, the application of the highest design standards would be expected to maximize safety. However, when operating under constraints, compromises on standards become necessary. A better understanding of the incremental and combined effects of roadway design features on safety is needed to guide decision making and promote highway safety management efforts. A considerable amount of research has been conducted to understand the effects of geometric and traffic features on safety. The results of that research need to be synthesized into a unified document and correlated with current design practice to allow development of a hierarchy of the relative safety benefits of highway design features. This will enable highway agencies to select design features that are essential to highway safety and allow comparisons among alternative investment policies that will optimize the overall safety of their highway systems in the real world of limited resources and other constraints.

The objective of this research is to assess the safety effects of highway design standards and to synthesize the findings into documents that will provide guidance in addressing safety needs, given limited resources and other constraints. The research should be limited to geometric, cross-sectional, and roadside design elements for all roadway types and environments. The composition of traffic and seasonal and daily variations is considered an important aspect of this research.

In order to meet the objective, the following Tasks are envisioned. (1) Review recent studies and current efforts to identify the critical variables and parameters associated with the relationship between design features and highway safety. (2) Contact state highway agencies and other organizations having road design responsibilities to review their processes and practices for the application of design standards for different classes of roads, varying traffic conditions, and other factors (e.g., safety analyses, design exception reports). (3) Critically review the information gathered to assess the usefulness of the relationships between safety and design features, the confidence in the data used to establish the relationships, the range of applicability, the soundness of procedures to apply the relationships, and the consensus among agencies. Synthesize the information gathered into a document that relates and assesses the effects of particular features on highway safety under varying conditions. Identify reasonable threshold values for design features that might be applied when resources are limited or other constraints are encountered. (4) Prepare an interim report which includes a synthesis document, identifies major deficiencies in the state of the art, and outlines methods to address the deficiencies. The contractor should prepare an outline for a user's manual to apply the findings of the synthesis and indicate the types of projects and associated situations planned as case studies in Task 5. An interim meeting will be held with the project panel to review the interim report. (5) Analyze case studies to indicate where planning and design decisions might have led to different outcomes, to test the usability of the synthesis information in the process, and to determine necessary changes to enhance usefulness. Prepare a concise user's manual which includes the results of the case studies as examples. Revise the synthesis document based on the findings of these case studies. (6) Submit the synthesis document and user's manual for review by selected AASHTO committees designated by the NCHRP. Respond to review comments and revise User's Manual as approved by the NCHRP project panel. (7) Develop an ordered list of research plans to address the deficiencies identified. The plans should indicate the critical factors to consider, data requirements, projected work elements, and associated costs. (8) Prepare a final report documenting the efforts undertaken and the findings of the study.

It was determined at the interim meeting that it would be premature to publish a user's manual. Research is continuing to address the gaps in knowledge identified.

Project 17-10 FY '94

Structural Supports for Highway Signs, Luminaires, and Traffic Signals

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	30 months
Completion Date:	
Funds:	$300,000

Since the 1985 edition of the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* was published, significant changes have occurred in design philosophies, material choices, and manufacturing processes for highway sign, luminaire, and traffic signal supports. At present, the specifications do not contain comprehensive criteria for all materials (e.g., design criteria for increasingly used fiber-reinforced plastic supports are not included). Moreover, some support components are not adequately addressed in the existing specifications, and the design criteria for oscillation, fatigue, and deflection need to be improved. Finally, the specifications should include SI units of measurement in anticipation of U.S. conversion to that system. Therefore, the specifications need to be updated, revised, and presented in a convenient format.

The objective of this research is to develop up-to-date, comprehensive specifications, and an accompanying commentary, for structural supports for highway signs, luminaires, and traffic signals for consideration by the AASHTO Highway Subcommittee on Bridges and Structures. These specifications—to be presented in SI units—shall reflect state-of-the-art design philosophies and manufacturing processes. Materials to be addressed include steel, aluminum, prestressed concrete, and fiber-reinforced plastic composites.

The research should make use of word-processing technology and any other techniques that will ensure state-of-the-art, user-friendly specifications that can easily incorporate future addenda and enhancements. The specifications will include cross-references, an index, and a commentary. It is further intended that, to the extent possible, the final report and specifications will eliminate ambiguities, conflicts, and oversights, and will provide appropriate definitions and support data.

It is anticipated that the research will include at least the following tasks:

Task 1. Review published research reports, specifications, and related documents pertaining to design concepts and materials for highway sign, luminaire, and traffic signal structures. Investigate current design procedures and manufacturing processes for highway sign, luminaire, and traffic signal support components. Review current FHWA requirements for breakaway supports. The results of Task 1 shall be summarized in appropriate Quarterly Progress Reports.

Task 2. Develop or refine design criteria for structural

components. Design criteria should address the following technical areas at a minimum: (a) Allowable dead load deflections for overhead and cantilever sign structures and mast arms for lighting and traffic signal supports; (b) Final deflected position of vertical and horizontal cantilevered supports under design loading; (c) Allowable bending stresses; (d) Allowable stresses for square and rectangular sections loaded across the diagonal; (e) Performance of anchorage systems (e.g., fatigue, combined loading, and embedment depth); (f) Drag coefficients for poles with shape-transition areas; (g) Height coefficients as a continuous function of elevation; (h) Oscillations as they affect fatigue, resonance, and public confidence; (i) Updated isotach maps; (j) Structural behavior of breakaway devices (e.g., allowable loads and fatigue considerations for transformer bases and couplings); (k) Connection techniques (e.g., welding, adhesives, and other fastening systems); (l) Span-wire design philosophies; (m) Corrosion-protection systems for structural components including the anchorage system; and (n) Foundation design philosophies.

Task 3. Identify and rank specification areas that need future research and modification beyond what will be accomplished in this project.

Task 4. Submit an interim report that documents the results of Tasks 2 and 3, includes a proposed format for the specifications and commentary, and proposes a detailed work plan for the remainder of the project. Following project panel review of the interim report, meet with the panel to discuss the interim report and the remaining tasks. NCHRP approval of the interim report will be required before proceeding.

Task 5. Following the approved work plan, develop and submit a draft of the recommended specifications and commentary. Supplement this draft with a separate document containing design examples, verifying that the specifications are accurate and user-friendly. NCHRP approval of the draft specifications, commentary, and design examples shall be required before proceeding with Task 6.

Task 6. Submit a final report describing the entire research effort. Include the revised recommended specifications and commentary as Appendix A and the design examples as Appendix B.

Project 17-11 FY '94

Determination of Safe/Cost Effective Roadside Slopes and Associated Clear Distances

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	24 months
Completion Date:	
Funds:	$250,000

The "clear zone" concept for roadside design emerged in the mid-1960s, when the idea of a single lateral distance beyond which any potential roadside obstacle did not require removal or protection was introduced. However, acceptance of a single distance for lateral clearance has diminished over time. Additional insight and guidance on roadside design was provided by the *Guide for Selecting, Locating and Designing Traffic Barriers* (1977). AASHTO's 1989 *Roadside Design Guide* provides the current guidelines for roadside recovery areas. The guidelines provide a range of values for recovery-area distances depending on traffic volume, design speed, side slope, and other roadside conditions that exist, or will exist, along the roadway. These guidelines are based, in part, on research undertaken for the 1977 *Barrier Guide* and on nationwide experience in applying the clear zone concept. Although these guidelines provide a more realistic approach than the application of a single distance, there are major concerns because the values are based on studies conducted many years ago that used relatively limited data and extrapolated numbers to cover a variety of roadside conditions.

Experience has also indicated that the recovery area provided along highways is usually not completely clear of all objects and often has side slopes greater than desired. Furthermore, transportation agencies frequently face difficulties in providing desireable recovery areas because of right-of-way constraints or construction costs. Consequently, current practice is to provide an area that provides a "reasonable opportunity" for a driver to regain a measure of control or to slow an errant vehicle. These areas are often referred to as "control zones" or "lateral areas." Updated guidelines are needed to aid designers in determining safe and cost-effective recovery areas, while recognizing the constraints associated with building or improving the highway system. Research is needed to evaluate recovery-area distance requirements for the full range of roadway classifications (from low-volume, low-speed to high-volume, high-speed roadways) to assist cities, counties, and state agencies facing critical highway-design decisions. These requirements will provide the basis for updating design guides and associated tools.

The objective of this research is to develop relation-ships between recovery-area distance and roadway and roadside features, vehicle factors, encroachment para-meters, and traffic conditions for the full range of highway functional classes and design speeds.

To accomplish the project objective, the following tasks are envisioned:

Phase I—*Task 1.* Conduct a critical review of pertinent literature and research in-progress on recovery-area distances for vehicles leaving the traveled way. The review should include, as a minimum, the effects of the following variables: design speed, traffic volumes, side slopes, roadside features (e.g., slope configuration, presence of objects), accident frequencies and severity, encroachment frequencies and conditions (e.g., speed, departure angle, yaw angle), roadway geometrics, and vehicle factors (e.g., type, safety equipment). Assess the strengths and weaknesses of the data

and the methodologies that have been used in previous and ongoing research in this area.

Task 2. Conceptualize a set of relationships for recovery-area distances that relate the variables identified in Task 1 and provide a basis for improved procedures for use by highway designers to determine safe, cost-effective roadside recovery areas. Assess the adequacy and availability of existing data to establish the recovery-area distance relationships conceptualized. Describe these relationships and their application in the highway design process in a working paper for review by the project panel.

Task 3. Develop relationships for recovery-area distances using the existing data identified in Task 2. Identify further data collection and analyses needed to strengthen or support the relationships developed from existing data. Also, outline methodologies to gather and analyze additional information needed to establish any new relationships to complete the conceptual set described in Task 2.

Task 4. Prepare a detailed work plan describing the rationale, methods, information sources, data-collection plans, schedule, budget and any special facilities, equipment, or arrangements required to develop and present updated recovery-area distance relationships.

Task 5. Prepare an interim report that summarizes the efforts and findings of Tasks 1 through 3 and includes the work plan prepared in Task 4. The interim report will be distributed to the project panel for review and comment. The contractor will be required to meet with the panel in Washington, D.C., to describe the efforts undertaken, present the findings, and outline the additional efforts that are necessary to strengthen, develop, and validate the recovery-area distance relationships. Discussions at the interim meeting may necessitate changes to the proposed work plan. Phase II of the project will not begin until the work plan is approved by the NCHRP.

Phase II—*Task 6.* Collect and analyze data in accordance with the work plan approved in Task 5. The contractor will be required to document the data gathered in this effort and deliver it to the NCHRP at the conclusion of this project.

Task 7. Develop the updated recovery-area distance relationships and conduct a sensitivity analysis of the individual components of the relationships.

Task 8. Provide 50 copies of a document describing the relationships and their application for an extended review by highway designers selected by the project panel. The NCHRP will distribute the document and summarize the comments made by the reviewers. The contractor will evaluate the review comments as summarized by the NCHRP and recommend modifications to the relationships and the report. Meet with the project panel to discuss which revisions should be incorporated into the final version of the report. Undertake the efforts necessary to make the revisions.

Task 9. Prepare a Final Report that describes the entire research effort.

AREA 18: CONCRETE MATERIALS

(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)

AREA 19: FINANCE

(For projects in this Area, refer to Summary of Progress Through 1988—Special Edition)

AREA 20: SPECIAL PROJECTS

Project 20-5 FY '68 and continuing

Synthesis of Information Related to Highway Problems

Research Agency:	Transportation Research Board	
Principal Invest.:	Sally D. Liff and Stephen Maher	
Effective Date:	December 15, 1967	
Completion Date:	Continuing	
Funds:	$100,000 annually,	FY '68-'71
	$200,000 annually,	FY '72-'75
	$300,000 annually,	FY '76-'77
	$330,000	FY '78
	$360,000 annually,	FY '79-'83
	$380,000	FY '84
	$650,000	FY '85
	$600,000 annually,	FY '86-'87
	$650,000	FY '88
	$550,000	FY '89
	$650,000	FY '90
	$600,000	FY '91
	$600,000	FY '92
	$790,000	FY '93
	$800,000	FY '94

Administrators, practicing engineers, and researchers are continually faced with highway problems on which much information exists, either in documented form or in terms of undocumented experience and practice. Unfortunately this information is often fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem is frequently not brought to bear on its solution. Costly research findings may be unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

In this project, particular highway problems, or sets of closely related problems, are designated each year as topics for information synthesis.

For each topic the objectives are:

1. To locate and assemble documented information.
2. To learn what engineering practice has been used for solving or alleviating the problem.
3. To identify all ongoing research.

4. To learn what problems remain largely unsolved.
5. To organize, evaluate, synthesize, and document the useful information that is acquired.
6. To evaluate the effectiveness of the synthesis after it has been in the hands of its users for a period of time.

Published syntheses of highway practice that have been prepared under this project are listed in Table 5. Additional information on the project may be found in Research Results Digest 195.

Project 20-6 FY '69 and continuing

Legal Problems Arising out of Highway Programs

Research Agency: Transportation Research Board
Principal Invest.: James B. McDaniel
Effective Date: November 1, 1968
Completion Date: Continuing
Funds:

$200,000 FY '69	$100,000 FY '82
$125,000 FY '72	$150,000 FY '83
$50,000 FY '73	$200,000 FY '84
$185,000 FY '74	$280,000 FY '85
$125,000 FY '75	$200,000 FY '86 & '88
$85,000 FY '76	$100,000 FY '89
$75,000 FY '77	$200,000 FY '90
$100,000 Ann. FY '78-'79	$175,000 FY '91
$150,000 Ann. FY '80-'81	$160,000 FY '92
	$100,000 FY '93
	$100,000 FY '94

A major and continuing need of state highway and transportation departments involves assembling, analyzing, and evaluating operating practices, administrative procedures, and legal issues associated with highway and transportation projects. Individual state legal experiences need to be compared and made available for possible wider application. Research to identify and evaluate legal options facilitates the handling of both immediate and long-range needs of engineering, planning, and administrative aspects of transportation programs.

NCHRP Project 20-6 was established in 1968 to meet these needs. It is a continuing study under the direction of the TRB staff Counsel for Legal Research. To date more than 90 study topics in the highway legal area have been researched under this project. More study projects are currently under contract for research or are pending selection of authors and execution of subcontracts. These studies are carried on at legal research centers or in transportation agencies throughout the United States.

Selected Studies in Highway Law (SSHL) was introduced by the Transportation Research Board in 1976 as part of NCHRP Project 20-6. It has been recognized as a significant contribution to the professional literature in this field. The term "highway law" embraces many branches of the law, including contracts, torts, eminent domain, evidence, and taxation. Although numerous texts and treatises have covered these traditional branches, none have given them the specialized treatment and orientation to transportation that is achieved in these works. This orientation is particularly important as transportation systems become more complex and represent greater investments of money and resources.

The purpose of *Selected Studies in Highway Law* (SSHL) is to furnish thoroughly researched reference material on highway and transportation law, either directly through work performed at its direction or indirectly through its function as a clearinghouse for identifying, using, and evaluating legal research from other sources. The focus of SSHL is periodically reviewed by an NCHRP Project Committee, which recommends critical problems for research in the fields of highway and transportation law. Therefore, research papers on these topics are prepared by the TRB legal staff or by consultants.

Studies completed under this project prior to November 1988 were published as *NCHRP Research Results Digests* (see Table 7). Subsequent studies are now published in a *Legal Research Digest* (see Table 8). Like previous papers published in the NCHRP Research Results Digest series, each issue of the Legal Research Digest focuses on supplements and new papers that will be compiled and subsequently published as addenda to the 4-volume compendium, *Selected Studies in Highway Law*. Because the material presented in these Digests will still be of interest to individuals in the transportation community who are not necessarily in the legal profession, they will continue to be widely distributed through the Transportation Research Board's selective distribution process.

Future work in this continuing project will include research on new topics of current interest in the legal field. Updating and supplementing the text book will continue. Additional information on the project may be found in NCHRP Legal Research Digest 24.

Project 20-7 FY '69 and continuing

Research for AASHTO Standing Committee on Highways

Research Agency: Open
Principal Invest.: Open
Effective Date: December 2, 1968
Completion Date: Continuing
Funds:

$100,000 annually	FY '69–'85
$56,000	FY '86
$150,000 annually	FY '87–'88
$125,000	FY '89
$200,000	FY '90–'91
$300,000	FY '92
$250,000	FY '93
$400,000	FY '94

The American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on

Highways is called on continually to rule on engineering and operations policies as a guide for State highway transportation departments to follow. The Committee desires to obtain guidance on a reasonably prompt schedule through a continuing research program geared to the needs and wishes of the Committee in the development of guides, standards, policies, and other AASHTO activities. In earlier years, objectives of the Committee were attained through the establishment of a continuing research capability at the Texas Transportation Institute (TTI) of Texas A&M University. In June 1973, the Committee stipulated that accomplishment of task research could be through any agency deemed by the NCHRP to possess the necessary expertise, provided the research could be initiated quickly.

The project includes a series of tasks specified by the Committee to obtain data required by the Committee to fulfill its responsibilities.

The status of current tasks completed after 1988 follows. For tasks completed prior to 1989, refer to the Summary of Progress Through 1988—Special Edition.

Task 30, "Manual on Subsurface Investigations." (Adrian Pelzner) The objectives of this task were to prepare the draft document developed under Project 24-1 for publication by AASHTO and to prepare a draft AASHTO standard for conduct of subsurface investigations. Research has been completed and the revised document was published by AASHTO in 1988.

Task 32, "Design and Construction Specifications for Segmental Concrete Bridges" (Post-Tensioning Institute). The objective of this research was to develop design and construction specifications for segmental concrete bridges. Research has been completed and the agency report was distributed to the program sponsors. The recommended specifications were adopted and published by AASHTO in 1989 as the AASHTO *Guide Specifications for Design and Construction of Segmental Concrete Bridges.*

Task 34, "AASHTO/AWS Bridge Welding Code Commentary and Draft Fracture Control Plan." (Warren G. Alexander) In 1988, AASHTO and AWS jointly adopted and published the *ANSI/AASHTO/AWS D1.5-88 Bridge Welding Code,* a new welding code for steel highway bridges. The objectives of Task 34 are to develop a commentary to the new code and to incorporate the welding related provisions of the 1978 AASHTO *Guide Specifications for Nonredundant Fracture Critical Members* into the code. The commentary has been completed and was published by AASHTO in early 1991. Work was initiated in late 1989 on the development of the welding provisions for fracture critical members. Several drafts of the fracture control provisions have been completed by the contractor and circulated for review by AASHTO and AWS. At a joint meeting of the joint AASHTO/AWS Bridge Welding Committee in February 1992, consensus was reached on the changes necessary for an acceptable draft of the fracture control plan. A revised draft was submitted for review by AASHTO and AWS at the end of August, and all work is now completed.

Task 35, "Review of Traffic Signal Intensity Standards." (JMJ Research) This task was requested by the AASHTO Subcommittee on Traffic Engineering. The objectives are to review existing traffic signal intensity standards and to prepare a report which can serve as a basis for the Institute of Transportation Engineers (ITE) to update and/or revise their standards of *Vehicle Control Signal Heads* to better meet in-serve performance requirements. The *Manual on Uniform Traffic Control Devices* (MUTCD) incorporates the intensity, light distribution, and color standards by reference to this ITE standard. This 12-month task was completed in March 1990.

Task 36, "Critical Assessment of Tire Pressure Research." (Harry A. Smith) This task was requested by AASHTO Joint Task Force on Pavements. A synopsis and critical evaluation of completed and ongoing research efforts pertaining to high pressure truck tires was developed and future research required to fill information gaps was identified. Research has been successfully completed, and the final report is available upon request.

Task 37, "Development of an Asphalt Paving Handbook." (TRB Division B) This task was requested by AASHTO Subcommittee on Construction and the Subcommittee on Materials. An asphalt paving manual geared to the needs of public agency field personnel and contractors involved in highway and airport construction has been developed and published. This effort was jointly funded by the National Asphalt Pavement Association (NAPA), AASHTO, FHWA, US Army Corps of Engineers, and the Federal Aviation Administration (FAA). The handbook is available through NAPA, AASHTO, APWA, and others.

Task 38, "AASHTO Guidelines for Pavement Management Systems." (ARE, Inc.) This task was requested by AASHTO Task Force on Pavement Management. The objective was to completely revise and expand the AASHTO *Guidelines on Pavement Management* (1985), incorporating the latest theory and practices. The new guide gives effective guidance to states that are in the early phase of Pavement Management Systems (PMS) development, guides states with existing systems toward state-of-the-art practices, identifies and encourages areas of uniformity of certain practices and data, and assists states in providing guidance to local transportation agencies. Research is complete, and AASHTO has published the new *Guidelines for Pavement Management Systems.* This task was expanded to allow participation of the research agency in the FHWA-sponsored "Advance Pavement Management Course." That involvement has been successfully completed.

Task 39, "Revision of AASHTO Pavement Overlay Design Procedures." (Darter and Associates) This task was requested by AASHTO Joint Task Force on Pavements. The objective was to revise Chapter 5 of Part III of the AASHTO *Guide for Design of Pavement Structures* so that pavement overlay design procedures will yield valid and acceptable designs. Chapter 5 addresses the subject of pavement design procedures for the rehabilitation of existing pavements with

overlays. The final report with recommended rewording of Chapter 5 and complete documentation has been completed, verified, and presented to the Joint Task Force. It has been adopted by AASHTO and is included in the latest version of the AASHTO *Guide for the Design of Pavement Structures.*

Task 40, "AASHTO Contribution to Support of the Highway Research Coordinating Council." (Mr. Lloyd G. Byrd) The objectives of this study are to assist the Highway Research Coordinating Council (HRCC) in analyzing the research activities of the major institutions involved in national highway research programs in the United States, to develop ways to display information for comparison of programs, to identify strategies for establishing and operating an Industry-HRCC, and to recommend improvements to the HRCC. This effort is being jointly funded by AASHTO, FHWA, and the US Army Corps of Engineers. The project is complete, and the final report has been distributed to the sponsors.

Task 41, "AASHTO Guide for Recruitment and Retention of Transportation Professionals." (Dr. Herb Golden and Ms. Leslie Collins) Study activity has been in support of the AASHTO Task Force on Civil Engineer and Transportation Professional Development and Recruitment. Activity thus far has included the hiring of a professional writer (Herb Golden) to assist in the preparation of The AASHTO *Guide to Recruitment and Retention of Civil Engineers* and to support the introduction of the *Guide* at the AASHTO Workshop on Transportation Careers held in Detroit, Michigan, on April 30 and May 1, 1990. Workshop support included a videotape of the Workshop to be used as reference material to the *Guide.* The Guide is available to AASHTO member departments. An additional objective was to provide assistance in developing pilot program material for the evolving AASHTO Transportation Civil Engineers (TRAC) Careers Center. Ms. Leslie Collins, a public relations consultant, was added to the research team to provide this assistance. TRAC has now become a pilot program fully within AASHTO. All task activity is complete.

Task 42, "Development of National Truck Size and Weight Policy Recommendations." (TRB Division B) The objective of this task is to assist AASHTO in carrying out Administrative Resolution AR-3-89 which establishes a goal of developing a set of national truck size and weight and related policy recommendations. Staff support assisted an AASHTO Ad Hoc Task Group on Truck Size and Weight Research and Policy in focusing on major issues critical to formulating truck size and weight policy. The Ad Hoc Task Group developed a list of priority issues and set forth recommendations in the form of AASHTO Resolution PR-5-90, which has been adopted by the policy committee. A resource document was prepared, and the Ad Hoc Task Group has issued a final report, "Truck Size and Weight Issues."

Task 43, "Revision of the AASHTO Policy on Geometric Design of Highways and Streets." Canceled.

Task 44, "Division 100 Revision of the AASHTO Guide Specifications for Highway Construction." (Trauner Consulting Services, Inc.) Several State highway agencies have in recent years revised their specifications to address the issues that have developed as a result of (1) legal interpretations of the issues coming from the courts; (2) changing methods of doing business in the fields of contract administration and construction inspection due to factors such as increased claims and new legislative requirements; (3) growing involvement of third parties in the control and inspection of construction activities; and (4) increased construction industry involvement in the control of material quality and construction procedures due to a decrease in the availability of experienced State field personnel. The AASHTO Highway Subcommittee on Construction requested a synthesis of Division 100 example specifications addressing areas such as claims handling, design-construct contracts, bid escrow documentation, construction inspection by consultant, quality assurance, etc., including the ramifications of these specifications on the state highway agency and the contractor. Based on this synthesis, a revised version of Division 100 was prepared and presented for consideration by the Subcommittee. Subsequently, the Subcommittee adopted the recommended version, with minor changes, for use in the next addition of the Guide Specifications.

Task 45, "Revisions to the AASHTO *Guide Specification for Seismic Design of Highway Bridges.*" (Dr. Ian G. Buckle) This task was requested by the AASHTO Highway Subcommittee on Bridges and Structures. The objective of the study is to provide recommended revisions to the seismic Guide Specification. The 1983 AASHTO *Guide Specification for Seismic Design* was based on work completed in 1981 by the Applied Technology Council under contract to the Federal Highway Administration. Since it was issued, relatively few revisions have been made to the Guide Specification. However, a substantial amount of new knowledge has been gained concerning the seismicity of the Eastern and Central United States since 1981. In addition, a significant amount of damage was sustained by bridges in California during the 1989 Loma Prieta earthquake. Finally, NCHRP Project 12-33, *Development of a Comprehensive Bridge Specification and Commentary,* which is developing a new probability-based bridge design specification for consideration by AASHTO, requires state-of-the-art seismic design information. Therefore, this task was initiated to provide the basis for reviewing and revising the provisions in the Guide Specification as necessary. The contractor has prepared a comprehensive list of changes that will be made to the specification. However, some of these changes will be dependent on research presently being performed for CALTRANS by the Applied Technology Council (ATC), and thus the task will not be completed until January 1994 in order to take advantage of CALTRANS efforts thru Fall 1993. Several versions of the revised specification have been reviewed and commented on to date. (Note: AASHTO adopted the Guide Specification as a Standard Specification in 1991. Therefore this effort will provide recommended revisions to the 1991 Standard Specifications.)

Task 46, "AASHTO Guidelines for Bridge Management

Systems." (The Urban Institute) The AASHTO *Guidelines for Pavement Management Systems* was published in 1990 based on work completed under NCHRP Project 20-7, Task 38. AASHTO also recognized the need and advantage of developing a companion guide document for Bridge Management Systems. The document will provide guidance to states that are in the early phases of Bridge Management System development, guide states with existing systems toward state-of-the-art practices, identify and encourage areas of uniformity of certain practices and data, and assist states in providing guidance to local transportation agencies. The project is completed, and AASHTO has published the document.

Task 47, "Support for the Joint Committee on Truck Size and Weight." (Dr. Michael D. Meyer) Responding to AR-3-89, AASHTO formed a Joint Committee on Truck Size and Weight, charged with the goal of developing a set of national truck size and weight and related policy recommendations. A Workshop on Truck Size and Weight was held on April 9–10, 1991, in Portland, Oregon. Dr. Meyer conducted a half-day presentation session and a full day working session toward the development of a comprehensive, strategic set of actions regarding truck size and weight, as well as a work plan leading to their implementation. A summary report of this workshop presenting the AASHTO strategy/work/implementation plan has been prepared and was reviewed by the Executive Committee on June 10 and by the Policy Committee on June 21, 1991. This task also supported Dr. Meyer's efforts in connection with his coordination of Task 50, which resulted in the completion and submission to AASHTO of a White Paper on the Feasibility of Longer Combination Vehicles.

Task 48, "Standard Specifications System Development for Uniform Location of Subject Matter." (The Construction Specifications Institute) At the September 5–6, 1990, meeting of the AASHTO Standing Committee on Research, consideration was given to Problem Statement 92-D-20, "Development of a System for the Uniform Location of Subject Matter Within Standard Specifications," submitted by California. This problem statement was endorsed via a resolution passed at the 1990 meeting of the AASHTO Highway Subcommittee on Construction (HSOC). SCOR agreed with the basic intent of the Problem Statement but believed a smaller, short-term preliminary effort to review and assess the impact of various standards on AASHTO and its membership would be more appropriate. Further discussion led to the suggestion that the problem would be more appropriate for consideration by the AASHTO Standing Committee on Highways through NCHRP Project 20-7. This task was established to accomplish that suggestion. The Construction Specifications Institute was selected to accomplish this task. Work was completed on schedule. Representatives from the research agency presented the results to the Highway Subcommittee on Construction during its 1992 summer meeting in Rapid City, South Dakota, and the Subcommittee has distributed the final report to its members to evaluate the recommendations and the desirability of modifying future editions of the AASHTO *Guide Specifications for Highway Construction.* Additional FY '94 funds were approved for a follow-on study to convert a draft guide specification on quality control and quality assurance (developed by the Construction Subcommittee) to the recommended numbering system and the imperative-mood writing style. An additional $5,510 was added to the original contract amount of $83,570 for this conversion. Work is expected to be completed by October 15, 1993.

Task 49, "Follow up on U.S.A. Asphalt Study Tour of Europe." In September 1990, individuals representing FHWA, NAPA, AASHTO, SHRP, TRB, and TAI visited six European countries to look at asphalt paving practices and results. The members of the study group in general were favorably impressed with certain aspects pertaining to asphalt pavements, and indicated an interest in investigating how these aspects could appropriately be implemented in the U.S. This task has been established to assist, as required, with appropriate investigation and implementation of concepts, where warranted. Coordination must be insured between this task and the research to be conducted under NCHRP Project 4-18, FY '92, "Design and Evaluation of Large Stone Mixtures," the work being done on stone mastic asphalt by several states, and the TRB Task Force A2T51 on Innovative Contracting Practices. A meeting was held during the 1991 TRB week, at which plans to construct a few test sections of SMA were discussed. Byron Lord is coordinating the FHWA efforts in this area. Funding was used for travel expenses for an engineer from the Colorado DOT to travel to the LCPC facility near Nante, France, for on-site inspection and training in connection with the asphalt testing equipment that is being purchased. A report on the equipment has been received and circulated to all members of the AASHTO Highway Subcommittee on Materials. Additional efforts under this task await an opportunity to assist states in this area. It is not certain that needs will develop or what may be involved. These funds can be used to follow up on either the asphalt or concrete European Tours.

Task 50, "White Paper on the Feasibility of Longer Combination Vehicles (LCV)." (Dr. Michael D. Meyer, Dr. Harry S. Cohen, and Dr. Paul O. Roberts) This paper was prepared to examine the state's implementation concerns of permitting LCV's on a national system. The impacts of such vehicle use were summarized, including increased productivity, pavement savings/costs, bridge costs, safety implications, traffic capacity and congestion, modal diversion, and environmental costs. State experiences where such vehicles are currently allowed were incorporated into the paper. Alternative means of allowing LCV's were examined, and guidance prepared to those states that are currently trying to respond to requests for such permitted use. The paper contains no specific recommendations, but instead, by presenting alternatives and discussing the pros and cons of each, governments currently facing decisions relating to LCV highway use have in one document suitable information that will

inform these decisions. A balanced team consisting of Dr. Michael Meyer of Georgia Institute of Technology coordinating the work of two independent consultants: Dr. Harry Cohen of Cambridge Systematics, Inc., and Dr. Paul Roberts of Transmode Consultants, Inc., who prepared the paper, which provides a valuable source document for the AASHTO Joint Committee on Domestic Freight Policy.

Task 51, "Synthesis of the Impacts of Truck Size and Weight on the Transportation System and the Economy." (Ms. Barbara T. Harder) Much research has been undertaken on the relationship between truck size and weight and the impacts on the transportation system and the economy. However, there is no one document that integrates all of the research findings in an easily understandable format. This synthesis has done just that. The synthesis provides a review of the literature and an overview of the research findings on critical topics in the area of truck size and weight as they relate to the transportation system and the economy. This synthesis is a valuable source document for the AASHTO Joint Committee on Domestic Freight Policy.

Task 52, "Support for the Joint Committee on Domestic Freight Issues." (Mr. Isaac Shafran) Responding to Resolution AR-2-91, AASHTO has formed a Joint Committee on Domestic Freight Policy. The Joint Committee, composed of more than 40 individuals, will be making decisions in a very contentious area. This funding is to provide help in digesting information and identifying the mission and needs of the Committee. The initial meeting of the Joint Committee was held on April 3, 1992, at which Mr. Shafran presented "A Review of National Domestic Freight Policy." During a subsequent meeting in Charleston, S.C., on July 24–26, 1992, Mr. Shafran assisted with the meeting and presented additional information. The AASHTO Subcommittee on Truck Size and Weight of the Joint Committee on Domestic Freight Policy has requested an expansion of the resource document, "Synthesis on Impact of Truck Size and Weight." The revised document has been completed and the project is completed.

Task 53, "Profilograph Limitations, Correlation and Calibration Criteria for Effective Peformance Based Specifications." (Mr. Larry Scofield) This task was requested by the Highway Subcommittee on Construction to resolve the high variability in manual reduction of tracings when using the California type profilographs and significant differences between automated profilograph and manual data reductions. The allocated funds are intended for an investigation to assess the nature of the problem and its extent. The output from this investigation should be a "synthesis" of the situation, compiling in a logical manner what has been done in this area, complete with a proposed solution or recommendations for research. The final report has been distributed.

Task 54, "Financial Impacts of Conversion to the Metric System." (The University of Alabama and Mr. Peter Smith) The AASHTO Standing Committee on Highway's Task Force on Metrication requested funding from Project 20-7 to assist in the identification of the factors that must be considered for conversion and to analyze cost impacts. The Task Force also decided that a "Guide to Metric Conversion" should be developed under this task to provide guidance to AASHTO and state and local transportation agencies on the steps, planning and procedures that will be necessary for conversion to metric. The procedures will emphasize aspects of cost minimization; i.e., methods for which unit costs and total costs at the state level can be minimized and possibly absorbed in existing budgets. The University of Alabama was selected to develop the guide document. In addition, a consultant from Ontario, Canada, was employed to document the steps, procedures, and engineering standards employed by the Province of Ontario during its conversion efforts in the mid-1970s. The draft guide was reviewed and approved by the Metric Task Force in October, and it will be submitted to the AASHTO Board of Directors for action by the end of 1992. In April 1992, the consultant provided a draft of recommended engineering standards, which was forwarded to the Subcommittees of SCOH by the chairman of the Task Force for review and comment. The draft guide was revised and approved by the Task Force and the 20-7 panel in December 1992. It was adopted by AASHTO and the project is completed. The report has been published by AASHTO.

Task 55, "Support for National Quality Initiatives." (Greenhorne and O'Mara, Inc.). This task was requested by the National Quality Initiatives Subcommittee for Quality Management specifically to support one or more conferences on Quality Initiatives directed at the Chief Executive Officers and top management of State Highway Agencies, contractors, and suppliers. Contract assistance with logistics, administrative details, invitations, registration, handouts, preparation of graphics, speaker's travel, etc., is required. The advisory panel for this task is the Management Working Group of the National Quality Initiatives Steering Committee. A significant workshop titled "Partnerships for Quality" is planned for Tuesday, November 10, 1992, at the Dallas/Ft. Worth Airport Hyatt. A report documenting the conference has been submitted and approved by the advisory panel. The agency assisted with the four regional workshops and portions of the report were distributed at the workshops. The project is completed.

Task 56, "Review of AASHTO *Standard Specifications for Highway Bridges* Foundation and Substructures Provisions" (D'Appolonia). The AASHTO Highway Subcommittee on Bridges and Structures requested this task to support an effort to review a large number of industry comments on the recently adopted revisions to the foundation and substructure provisions in the AASHTO *Standard Specifications for Highway Bridges.* A consultant will review a substantial amount of technical material and provide recommendations on whether and how any specification provisions should be modified. The consultant worked with representatives of the Bridge Subcommittee and prepared modified specification provisions. These provisions were

reviewed and approved by the Bridge Committee during the May 1993 meeting. The project is complete.

Task 57, "Joint Task Force on Pavements' Workshop on SHRP LTPP Data and Analysis" (Mr. Kenneth H. McGee). The Joint Task Force defined a need for a workshop to develop a vision for appropriate use of SHRP LTPP data and other research results toward the needs of the pavement engineering community. A facilitator was hired to assist the Joint Task Force in organizing the workshop and prepare a plan and comprehensive cost estimate of the workshop. The facilitator made all arrangements for the workshop, which was held March 3–5, 1993, in Syria, VA. Invitations were issued and the workshop was attended by 40 pavement design engineers from the states, FHWA, and Canada. Four university faculty acted as recorders. The facilitator will prepare oral and written reports of the workshop results. Funding for participant travel had been allocated to ensure full participation. The draft final report has been reviewed and the consultant is revising the document. Research needs have been identified and the Joint Task Force on Pavement Design will work with the consultant on preparation of second-stage problem statements.

Task 58, "Information and Evaluation of Asphalt Rubber Research." As a result of provisions in the Intermodal Surface Transportation and Efficiency Act of 1991 (ISTEA), state highway agencies will be required to construct pavements with asphalt rubber, and there is a mandate for research in this area. Research will be done by FHWA, possibly in conjunction with the EPA, and a pooled-funds effort focusing specifically on asphalt rubber is being initiated. AASHTO member departments need information on the scope of these FHWA efforts. The AASHTO Standing Committee on Research, at its September 9–10, 1992, meeting, decided to earmark $100,000 for this task to allow an agency or consultant an opportunity on behalf of AASHTO to look at the ongoing research efforts in the area of asphalt rubber, to keep the states informed, and to seek research gaps that could be filled by NCHRP or other research projects. In addition to monitoring studies on engineering issues related to pavement performance, specific interest should be focused on research into the environmental and health considerations in recycling asphalt pavements containing rubber. The contract is pending.

Task 59, "Transportation Investment and Economic Expansion: Case Studies." The AASHTO Special Committee on Economic Expansion and Development in September 1992 specified as one of the objectives, in its "Strategic Plan for Continuing Activities," the development of a set of practical case studies based on state experiences. The case studies would then be used to help AASHTO and member states focus on priority issues for post-ISTEA actions as well as practical applications. The objective of this research is to summarize, in simple and understandable language, available information on the linkages between transportation infrastructure investment and economic expansion to help improve transportation investment decisions. The research approach will be based on a review of the fundamental ways in which transportation investment influences the economic development process in today's policy environment. An advisory panel was formed and it developed a work statement. The consultant was selected and the project is underway.

Task 60, "Support for Implementing the Clean Air Act Amendments of 1990." In recent times, nothing has had the potential to impact the provision of transportation facilities and services like the Clean Air Act Amendments (CAAA) of 1990. To meet the challenge presented by the CAAA and to do their share in providing clean air, state DOTs need a common, comprehensive, overall plan to guide their actions. In the end, state DOTs want to strike a responsible balance among environmental, economic, and mobility needs. To accomplish this, they need to develop partnerships between public and private sectors and involved public interest groups. It is imperative that state DOT forces and other concerned personnel be provided with the most current information on activities to implement the CAAA. Decision makers, such as transportation Chief Administrative Officers (CAOs), governors, and state and federal lawmakers and regulators, also need better and more complete information about the CAAA and the role of transportation in the implementation of the Act. The objective of this effort is to help the state DOTs implement the CAAA by providing complete and accurate information and developing educational packages to show the DOTs how to use this information constructively. In the short term, information dissemination is probably the most timely and cost-effective action that will help the state DOTs. Most of this information will come from areas that are new to the states, necessitating practical guidance. This project was initiated by the AASHTO Standing Committee on Environment. An advisory panel has been formed, selected agencies were asked to submit proposals, and the advisory committee is in the process of selecting a contract research agency.

Project 20-19(2) FY '86

Pedestrian Safety and Convenience on Suburban and Rural Highways—Implementation Phase

Research Agency: JHK and Associates
Principal Invest.: Steven A. Smith
Effective Date: September 1, 1987
Completion Date: December 31, 1989
Funds: $146,218

The first phase of this project, NCHRP Project 20-19, resulted in the publication of a two-part report, NCHRP Report 294A (Research Report) and NCHRP Report 294B (State-of-the-Art Report). This implementation phase, NCHRP Project 20-19(2), is envisioned primarily as a series

of efforts to support the implementation of the principles from Reports 294A and 294B.

Task 1 has developed several teaching modules suitable for integration into highway and planning courses at universities or at professional meetings. The Federal Highway Administration (FHWA) will be incorporating this material into one or more National Highway Institute (NHI) training courses.

Task 2 developed an "other markets" publication consisting of a condensed and more focused version of the reports from the first phase. This publication focused on the planning and development audience and will be implemented through channels appropriate to that audience.

Task 3 prepared a number of short articles to bring pedestrian needs and planning solutions to the attention of advocacy groups. Some of the articles will be published in forthcoming issues of TRB's magazine, *TRNews*.

Task 4 developed a 20-minute video, *Think Pedestrian.* The video is suitable for a variety of audiences, ranging from citizens who want to know more about good pedestrian planning and design practices to planning and engineering professionals who may not deal with pedestrians every day but yet require a basic knowledge of planning and design practices.

Task 5 developed a practitioners manual not only as a resource for the Task 1 training materials but also as a standalone document for planning and engineering practitioners. This document will be used by FHWA in the NHI courses.

All tasks have been completed. Loan copies of the written material are available from NCHRP. The *Think Pedestrian* video is available for purchase.

Project 20-23 FY '88

Kinematic Differential GPS Satellite Surveying

Research Agency:	GPS Services Inc./National Geodetic Survey
Principal Invest.:	Dr. Gerald L. Mader
Effective Date:	September 15, 1988
Completion Date:	September 14, 1990
Funds:	$298,793

Although the Navigation Satellite Timing and Ranging system (NAVSTAR), also known as the Global Positioning System (GPS), is a satellite system being developed by the Department of Defense under Air Force management, some civilian applications are allowed. Presently, six satellites providing positioning information are in orbit. This six-satellite constellation can be used for measurements only during a limited time each day. An eighteen-satellite constellation providing 24-hour coverage is expected to be fully operational between 1990 and 1992; this will then provide very precise three-dimensional information on a continuous basis.

Equipment presently on the market can provide coarse-point-positions (positioning with a single receiver) in real-time with accuracies ranging from an estimated 10 to 30 meters. Improvements in coarse GPS real-time point-positioning are expected to evolve within private industry because of the potential for widespread commercial applications. Coarse-point-positioning data can be used by DOTs with a geographic information system (GIS) for such activities as highway inventories, accident locations, and maintenance operations. Because systems that may provide levels of accuracy acceptable for some of these activities already exist or are expected soon, no research is proposed in this area. However, opportunities do exist in the area of precise relative positioning using GPS.

Use of the present satellite constellation has shown that relative positioning measurements with accuracies of a few parts per million are possible in 30 minutes or less of data acquisition. Preliminary work involving the use of GPS for rapid differential (kinematic) positioning of ground-based survey points has indicated the feasibility of greatly reducing the time required to accomplish the equivalent of geodetic traversing. This process uses the differential GPS measurement mode where the time needed for static data collecting over each point is measured in seconds instead of minutes or hours. The benefits of such a process are great when considering the amount of geodetic traverses being conducted by the DOTs.

Another application of kinematic differential GPS is the positioning of moving sensors, such as aerial mapping cameras. A prime potential benefit of this application is that of greatly reducing the need for establishing and targetting ground control points for photogrammetric mapping. Preliminary altimetry experiments have substantiated GPS-determined vertical positions to 10-cm accuracy. Current experiments are expected to show similar results for horizontal positioning. The benefits of this procedure could greatly reduce surveying costs for photogrammetric mapping. More work is necessary if state DOTs are to realize these benefits as soon as possible. Consequently, the objective of this research will be to determine appropriate algorithms and develop operational software for kinematic differential GPS positioning at the 1-cm to 2-cm accuracy level.

Research is complete. Research Results Digest 185, "NCHRP Supports Advances in Differential GPS Satellite Surveying," provided a preliminary announcement on the availability of software. Subsequently, more complete documentation has been submitted and is being evaluated by the NCHRP. An updated Research Results Digest is expected.

Project 20-24 FY '88

Research Program Design—Administration of Highway and Transportation Agencies

Research Agency:	Apogee Research Inc.
Principal Invest.:	Richard R. Mudge John A. Clements

Effective Date: May 11, 1987
Completion Date: September 30, 1988
Funds: $125,000

Much of the research conducted by the NCHRP is designed to solve specific problems, experienced by practitioners, that are related to the operational and planning functions of state highway departments. Although top management is certainly affected by these problems and benefits from solutions through improved agency performance, this type of research does not necessarily address top management's most immediate needs. A research program designed from the perspective of top management would help provide a needed resource to support the decisions and improve the effectiveness of top managers. Such a program was initiated under this NCHRP project.

Through surveys and interviews, issues of greatest concern to top management were identified. Individual projects were developed to address these issues and then described to provide background information and suggested research plans. All of the projects were classified under one of three categories—resource development, decision support, or financial management.

Research is complete, and the principal findings and brief summaries of all the recommended projects have been published in NCHRP Research Results Digest 170, "Research Program Design, Administration of Highway and Transportation Agencies." Additional details on the recommended program and the specific projects are available in the agency final report titled, "NCHRP Project 20-24, Research Program Design." The agency report was distributed to NCHRP sponsors only. However, others may obtain copies or purchase ones for the cost of reproduction (see final page of this section for ordering information).

The responsible NCHRP project panel remains active, meeting annually to decide on new projects. An updated summary of activities has been published as Research Results Digest 193, "Administration of Highway and Transportation Agencies, 'Project 20-24 Series'."

Project 20-24(1) FY '89

Using Market Research to Improve the Management of Transportation Systems

Research Agency: Apogee Research, Inc.
Principal Invest.: Dr. Richard R. Mudge
Effective Date: October 1, 1988
Completion Date: September 30, 1989
Funds: $199,923

Transportation programs must survive in an increasingly competitive world of public policy, where tough choices must be made among public works, social programs, tax cuts, and a variety of other public functions. Budget pressures are merely the most obvious outward sign of these political and financial battles.

Developing a political consensus for the funding of transportation programs requires both an in-depth knowledge of what the public knows about transportation and what their attitudes are about the transportation problems they face every day. Modern market research techniques, including public opinion surveys and focus groups, may offer a systematic way to help provide CAOs with answers to these questions.

Private firms make considerable efforts to identify their customers' general likes and dislikes as well as to identify specific needs. Based on this information, firms design a product or service to meet the potential customer's perceived needs and then work to convince them to purchase these products or services. As with other areas of modern life, marketing has become more sophisticated and technically advanced. How can these advances be adapted to help solve the problems of state DOTs?

While the focus of recent efforts in market research has been on surveys of public feelings in general, some of the same techniques could be used to survey and assess the needs and understanding of firms or groups with a direct interest in transportation. Most such information is now presented to DOTs by trade groups, but use of the ideas discussed here might make it possible to obtain information from the public at large.

Consequently, the object of this research was to help state DOTs to add modern market research techniques to their program development and evaluation methods.

Research is complete, and the final report has been published as NCHRP Report 329, "Using Market Research to Improve Management of Transportation Systems."

Project 20-24(2) FY '89

Executive Management Information Systems for State Departments of Transportation

Research Agency: Andersen Consulting
Principal Invest.: Roger A. Gelfenbien
Effective Date: May 1, 1989
Completion Date: October 14, 1989
Funds: $100,000

Providing relevant, accurate, and timely information in an easy-to-use format benefits any executive, primarily ones with the breadth of responsibilities found in transportation departments. Executive Management Information Systems (EMIS) are relatively new to departments of transportation and as such AASHTO requested a project to develop guidelines to assist member departments in the development and implementation of EMISs. The objectives of the project were to: (1) develop a prototype to assist DOT executives in understanding what an EMIS can do for their departments, and (2) outline the step-by-step process that would be needed to design, implement, and support an EMIS.

On behalf of the NCHRP, the contract research agency

worked with an AASHTO task force to develop a guide for implementing executive management information systems in state DOTs. Work is completed, and the agency's final report has been submitted. Copies of the report were sent to all state DOTs. Additional copies or copies to others are available for loan or purchase on request to the NCHRP. Research Results Digest 173, summarizing the work, has also been prepared and distributed.

Project 20-24(3) FY '90

Expanding the Civil Engineering Pool

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. John M. Mason
Effective Date: July 1, 1990
Completion Date: December 31, 1993
Funds: $200,000 (Phases I & II)
$100,000 (Phase III)

While recognizing the expected diverse demographics of our future population, the overall objective of the project was to recommend various implementable actions that will improve not only the number of civil engineers interested in transportation careers, but also the quality of those engineers.

Under a first phase, PTI catalogued and described existing techniques that are now being used to promote student awareness of civil engineering career options and interest in mathematics and science studies. Programs designed to address employee shortages in other professions were studied to benefit from any solutions to similar problems. Also under this phase, 17 focus groups at 4 locations were conducted with students (including women and ethnic minorities), teachers, parents, and counselors. The purpose of the focus groups was to gain insight into attitudes on civil engineering as a profession and career option.

Under a second phase and based on the results of the first phase, PTI recommended a series of actions that span kindergarten through college. Recognizing that there are other programs to promote mathematics and science, the degree to which these recommended actions stress civil engineering as a career option increases as the level of education increases. These various actions have been categorized under three themes: Awareness, Retention, and Curriculum, and are now referred to as the ARC model. The results of the first two phases have been published in NCHRP Report 347, "Civil Engineering Careers: Awareness, Retention, and Curriculum."

Under a third phase, various actions of the ARC model were advanced by providing more specific instruction on application and implementation and resulted in a comprehensive "User's Guide." Furthermore, the existing actions and techniques identified in the earlier phases were presented in a new "Directory" using the ARC framework. This phase is essentially complete. The Users Guide and the Directory are now being edited by the NCHRP.

Project 20-24(3)A FY '92

Civil Engineering Careers in Transportation—Outreach Program

Research Agency: AASHTO—TRAC Careers Center
Principal Invest.: Alan Shute
Effective Date: May 1, 1992
Completion Date: August 31, 1993
Funds: $100,000

The Pennsylvania Transportation Institute (PTI) at The Pennsylvania State University has completed the first two phases of the three-phase NCHRP Project 20-24(3), "Expanding the Civil Engineering Pool." The overall objective of the project grew to include recommendations on various implementable actions that will improve not only the number of civil engineers interested in transportation careers, but also the quality of those engineers and the recognition of the diverse demographics of our future population.

Under the first phase, PTI catalogued and described existing techniques that are now being used to promote among students an awareness of civil engineering career options as well as those techniques that provide an awareness for mathematics and science studies. Programs designed to improve on employee shortages in other professions were included to benefit from any similarities in the problem and its solution. Also under this phase, 17 focus groups at 4 locations were conducted with students (including women and ethnic minorities), teachers, parents, and counselors. The purpose of the focus groups was to gain insight into attitudes on civil engineering as a profession and career option.

Under the second phase and based on the results of Phase I, PTI recommended a series of actions that span kindergarten through college. Acknowledging other programs to promote mathematics and science, the degree to which these recommended actions stress civil engineering as a career option increases as the level of education increases. These various actions have been categorized under three themes: *A*wareness, *R*etention, and *C*urriculum, and are now referred to as the ARC model.

Additional research under a third phase is also planned to further advance various actions of the ARC model with more specific instruction on application and implementation.

In addition to the research just described, the NCHRP is aware of a unique opportunity to advance specific portions of the ARC model with the actual development, application, and evaluation of prototype material. A pilot program has recently been created by the American Association of State Highway and Transportation Officials (AASHTO), with principal funding from the Federal Highway Administration, although several other organizations are also providing financial support or making in-kind service contributions. This pilot program, which is a possible delivery mechanism for the prototype material, is called the TRAC (*Tra*nsportation and *C*ivil Engineering) Careers Center.

The TRAC pilot program will provide advice and coordination for outreach activities on a national level. However, the primary implementation of specific outreach activities will be accomplished by approximately three, to-be-selected, regional TRAC centers. These regional TRAC centers will be administered by university transportation centers, state departments of transportation, or a combination of both. For purposes of the pilot program, the outreach activities will be directed toward college-bound senior high school students. If the pilot program is successful, the intent will be to continue with the national effort and establish a network of regional centers.

Consequently, AASHTO will develop prototype material through its TRAC Careers Center under NCHRP Project 20-24(3)A. AASHTO/TRAC Careers Center competitively selected The Naidus Group to do the actual work. The specific objective of Project 20-24(3)A will be to develop prototype material for TRAC and to recommend suitable delivery mechanisms and evaluation criteria. The overall scope will include concept, development, design, and recommendations for distribution and evaluation.

All basic contract work is completed. AASHTO/TRAC, through The Naidus Group, has developed prototype material and guidance. Four regional TRAC centers are using and testing the material and guidance. Consequently, the final product for the research is being used directly and immediately by AASHTO. The principal investigator will prepare a summary of the effort for wide distribution under the NCHRP.

Project 20-24(4) FY '91

Senior Executive Service, Participant's Manual

Research Agency:	Braun, Johns, and Golden (Individual/Consultants)
Principal Invest.:	Mr. Richard P. Braun Mr. Robert C. Johns Dr. Herb Golden
Effective Date:	July 1, 1990
Completion Date:	April 30, 1991
Funds:	$25,000

In recent years, turnover among chief administrative officers (CAOs) of transportation agencies has been occurring at a frequent rate. At the same time, there has been an increase in the number of CAOs appointed with limited or no prior transportation experience. As a result of these combined trends, it has become important to establish programs to support CAOs from the outset.

Because no consistent experience or job background criteria are used to select new CAOs, there is wide variation in the kinds of specific skills and experience brought to office by new appointees. While each CAO has unique strengths to contribute to the management of his/her department, undoubtedly many will have less experience in some key areas. These areas will need to be reinforced, and the skills of the CAO complemented, so that the management unit is complete and can collectively handle all tasks basic to its effective functioning without the costly delays of a protracted transition and learning period.

A senior executive service (SES) comprised of ex-CAOs of state departments of transportation could offer management support to current CAOs through face-to-face visits or other means. SES participants acting as mentors or advisors not only would help new CAOs to quickly orient themselves to their positions but would also offer support on an ongoing basis.

The development of an instructional manual for use by potential SES participants would be a first step toward implementing the SES. The manual would be designed to assist and prepare the SES participant for subsequent interactions with the new CAO. The manual would need to include, as a minimum, preparations and tactics for the initial contact, briefing material, assessments of his/her own strengths and weaknesses, essential topics for discussion, methods for future follow-up and support, and the identification of any tools or support material, such as videotapes, books, contacts, etc.

In addition to or as part of the manual, there must be some guidance on how to match SES participants with new CAOs based on such possible factors as personality, age, region of country, and type of organization. Furthermore, to assist in making the match and to facilitate the conduct of meetings, preparatory material to be used by the new CAO will need to be developed. For example, a skills assessment inventory could be performed by the new CAO to assess his/her personal strengths and weaknesses and those of his/her staff as they relate to the effective functioning of the DOT.

Mechanisms for implementing the SES must also be considered as part of the study. Comments on various options will be expected.

Research is complete; camera-ready copy of the final report, now called "AASHTO's Transportation Leadership Program, Senior Executive Support Program, Participant's Manual," has been sent to AASHTO. AASHTO will incorporate the essence of this research into an AASHTO publication.

Project 20-24(5) FY '91

Public Outreach in Transportation Management

Research Agency:	Frank Wilson & Associates, Inc.
Principal Invest.:	Dr. Gary Edson
Effective Date:	August 1, 1991
Completion Date:	January 31, 1993
Funds:	$99,974

Many transportation departments are concerned that the public is relatively uninformed about such issues as how transportation facilities and services are financed, how they

are provided, how well they function, and, in general, the importance of an effective transportation system. It is also perceived that the general public has little understanding of such things as the respective roles of federal, state, and local governments and the financial mechanisms being employed to operate and maintain these transportation facilities and services. This limited understanding complicates the process of consensus building in the provision and operation of the transportation system.

It is vital, first, to understand what the public thinks about how transportation is provided and what their feelings are regarding the adequacy of the system and how best to improve it, and, second, to develop and implement techniques for communicating the needed information to fill the identified gaps. In response to the first step, a previous NCHRP project identified and described various market-oriented research techniques and included a demonstration of a nationally conducted public opinion survey. The results of that project are described in NCHRP Report 329, "Using Market Research to Improve Management of Transportation Systems."

Further activity in this area should now be directed toward using the results of market research, as well as the results of other techniques that have identified communication needs, to help design consumer-oriented programs to communicate with various audiences. Special emphasis must be placed on techniques to enhance interaction with the public on the development of policies, plans, and programs; the provision of facilities and services; and the performance of the transportation system. This will involve the identification and review of different techniques to assist transportation departments in implementing their own programs. A more effective public outreach program will assist in developing more responsive policies, building consensuses, and designing programs that are both effective and likely to gain broad support.

The first objective of this project is to recommend to state transportation departments programs and techniques to better inform the public of transportation issues. These programs and techniques must be sensitive to the ability of various audiences to understand complex transportation issues. Key aspects, which should be considered, are cost-effectiveness, ease of administration, and the effectiveness of the communication. The second objective is to demonstrate, by example, the effectiveness of public outreach communication techniques and programs.

Accomplishment of these objectives required the following tasks: (1) Identify problems of communication between state transportation departments and the public based on opinions of senior state DOT managers and other information sources. (2) Assemble a "toolbox" of techniques for communicating with various audiences. The overall toolbox concept will be consumer-oriented and include an explanation of the relevance and importance of employing market-oriented techniques for different transportation issues and audiences. (3) Propose a prototype communication package of selected outreach techniques that will most effectively demonstrate the power of market-oriented communication techniques for a particular transportation issue or theme. Submit the general description of the package and the reasons for its selection to the NCHRP for approval before commencing with subsequent tasks. (4) Develop the communication package prototype including an implementation plan, example material designed to inform the audience appropriate for the issue, and methods for evaluating its effectiveness. (5) Demonstrate the prototype at, or in conjunction with, an AASHTO meeting involving top level managers of state transportation departments. Based on these demonstrations, make necessary refinements to the prototype, and toolbox if necessary. (6) Prepare a final report that fully documents the conduct of the research.

The research is complete. A final research report and a handbook were produced. A videotape of three presentations made at the October 1992 AASHTO annual meeting to demonstrate successful public outreach techniques has also been produced.

The NCHRP will publish the handbook, now in the editorial stage, in the NCHRP series and make the final research report and videotape available on a loan or a permanent basis by request.

Project 20-24(6)A FY '91

Performance Measures for State Highway and Transportation Agencies

Research Agency:	Highway Users Federation for Safety and Mobility
Principal Invest.:	Marshall Reed
Effective Date:	August 1, 1991
Completion Date:	June 2, 1993
Funds:	$84,891

Recent trends reveal a high rate of turnover in chief administrative officers (CAOs) of state highway and transportation agencies. New CAOs must step in and manage vast organizations with numerous functions and organizational units. To do this effectively, a new CAO, and in particular one from outside the organization or even outside the transportation industry, must know how well the agency is currently performing as a whole and within each unit. Agency-performance information is also a powerful analytical tool for experienced CAOs in tracking their own performance over time and, perhaps, for generally comparing their state to others.

Under this project, a compendium of performance measures and indicators to assist state highway and transportation departments and their CAOs in evaluating and continuously improving the operational performance of their agencies was developed. In addition to the compendium, commentary on the use of performance measures and indicators is provided and directed primarily to CAOs and other top managers.

Research is complete, and the final report has been pub-

lished as NCHRP Report 357, "Measuring State Transportation Program Performance." A supplemental report titled, "Exploring Methodologies for Comparing State Highway Performance," is also included in the NCHRP report. A follow-on study was requested by the American Association of State Highway and Transportation Officials as a result of interest in a published ranking of the overall performance of state departments of transportation. The purpose of the study was to comment on the practice of comparative evaluations and to explore the feasibility of making valid comparisons.

Project 20-24(6)B FY '91

Business Systems Plan for Highway Engineering Information

Research Agency: PRODATA, Inc.
Principal Invest.: Ted Downey
Effective Date: August 26, 1991
Completion Date: October 31, 1992
Funds: $149,977

The American Association of State Highway and Transportation Officials (AASHTO) and its member departments have traditionally developed information systems supported by computer software and equipment on a bottom-up, project-by-project basis. However, as systems grow in this manner, the ability to share data and logically integrate systems becomes seriously constrained, and modifications are expensive. Furthermore, development of information systems in this bottom-up approach has been carried out in the absence of a top-down, information-systems master plan, i.e., a business systems plan.

In the past, highway engineering has been the principal focus of information systems. However, the management of information has increased in complexity, now that many state transportation departments are becoming truly multimodal, and can directly affect a department's organizational structure and influence the tools necessary for operating the department "business areas."

In recognition of existing and emerging situations, the management of transportation information needs to be analyzed using a top-down approach that recognizes all business areas of state transportation departments. Although an in-depth analysis of the management of information in all business areas is desirable, resources available to this project are limited. Therefore, because the traditional emphasis has been on highways, and this is the most immediate need to AASHTO, the research envisioned will concentrate primarily on the highway engineering system (HES) component of state transportation departments.

A business systems plan for the HES would show where AASHTO's in-house information-systems efforts could complement member department's information-systems efforts and, thus, avoid duplicative, expensive development activities. At the same time the plan would be generic and flexible, so that it could be easily modified to meet particular agency needs and changing conditions, and serve as an example for other transportation department business areas or modal systems.

Accordingly, an information-engineering methodology, including the identification of computer-aided software engineering (CASE) tools, should be used in the development of the business systems plan for the HES. This plan will provide a high level view of the relationship of HES information to the various business areas of state transportation departments and within the HES itself. A firm foundation, or blueprint, can thus be established for future information-systems developments and extensions, both software and hardware, or for making changes in existing systems. Central to the plan will be the definition of an architectural framework—a series of models—describing the required information and the various relationships and uses.

The objectives of this study were to: (1) define business areas for typical state transportation departments, and (2) develop a business systems plan for support of all engineering functions necessary for the design and construction of highway projects. The accomplishment of these objectives required the application of an information-engineering methodology and the completion of at least the following tasks:

Task 1. Develop and describe the information-engineering methodology to be used to accomplish the project objectives.

Task 2. Assess current and future organizational structures of typical state transportation departments. Make direct contact with at least 15 state transportation departments representing a range of sizes and geographic locations.

Task 3. Apply the Task 1 methodology to identify typical business areas and the highway engineering system component. Describe each business area and the HES in terms of functions, processes, data entities, and their relationships. Include generic descriptions of various CASE technologies that will assist in the management of information and the development of other needed software for the business areas and the HES.

Task 4. Develop the business systems plan to assist the American Association of State Highway and Transportation Officials and its individual member departments. (The plan will provide guidance for the logical and orderly development or selection of various computer software products and equipment for designing and constructing highway projects and for establishing linkages to the other activities and business areas.)

Task 5. Prepare a final report describing the research effort and include the business systems plan as a stand-alone appendix.

A draft final report was submitted, but based on NCHRP review comments, the agency has undertaken a significant rewrite. Contract time and funding have lapsed; however,

the agency assures the NCHRP that a satisfactory report will be produced.

Project 20-24(7) FY '91 & '92

Alternatives to Motor Fuel Taxes for Financing Surface Transportation Improvements

Research Agency:	Cambridge Systematics, Inc.
Principal Invest.:	Arlee T. Reno and Dr. Joseph R. Stowers
Effective Date:	March 1, 1992
Completion Date:	December 31, 1993
Funds:	$300,000 (Phase I—$175,000 and Phase II—$125,000)

Current revenue sources for providing, maintaining, and operating an effective surface transportation system are inadequate to meet present and projected needs. Petroleum-based motor-fuel taxes, the mainstay of the traditional user-charge approach to highway funding in the United States, have not kept pace with either need or inflation. However, until recent times, the taxation of motor fuels had been a reliable, economical, and comparatively popular method. Furthermore, the federal government and many state governments deposit these revenues in dedicated accounts embracing a user-fee approach to transportation improvements and producing a reliable flow of funds that facilitated long-range planning and programming. Now, a number of factors are reducing the effectiveness of motor fuel taxes as the primary financing mechanism for highway and other surface transportation improvements.

Continued improvement in motor-vehicle fuel efficiency and the development of alternatives to petroleum-based fuels diminish the effectiveness of motor fuel taxes as a measure of highway use and have a net effect of reducing expected revenues. Although the need is recognized, compensating increases in the fuel tax at both the federal and state levels are often difficult to enact.

Furthermore, motor fuel taxes are used increasingly to implement national policies on energy issues, on environmental concerns, and for budget-deficit reduction. Notwithstanding the importance of other national policies, this practice reduces the amount of motor fuel tax receipts available to transportation and erodes the concept as a dedicated fund comprised of user-fees.

Moreover, state and local governments are having to assume increasing responsibilities for funding the surface transportation system. This will require that innovative approaches be taken to ensure adequate funding, using new technologies and ideas to provide opportunities for new pricing and financing mechanisms.

Given these emerging trends, existing methods may need to be improved or new methods developed for financing the surface transportation system. Alternatives and their consequences must be identified and evaluated to assist public officials in making decisions on the future of the surface transportation system.

The objective of this research is to identify and evaluate alternatives to the traditional motor-fuel tax as a principal method for financing the surface transportation system. Alternatives will need to be evaluated within the context of a range of possible, future scenarios. The research should also consider the role of the user-pay principle in financing the surface transportation system and give adequate attention to financing mechanisms at all levels of government. Accomplishment of this objective will require, as a minimum, the following tasks:

Phase I

Task 1. Identify and describe existing conditions and problems of financing the surface transportation system primarily with motor fuel tax revenues. Describe the short- and long-term impacts of the current approach.

Task 2. Identify significant existing and potential alternative financing methods, including user-related and general revenue sources at all levels of government. Relevant foreign experience shall be considered. List and describe in detail financing alternatives beginning with more effective use of existing methods.

Task 3. Describe a limited number of future scenarios affecting the financing of the surface transportation system. These scenarios must encompass various possibilities, ranging from the extension of present trends to a scenario under which the total replacement of fossil fuels has occurred.

Task 4. Specify criteria and develop a framework for evaluating alternative financing methods. The criteria and framework shall include, but not be limited to, the following: economic and environmental issues, equity, administrative requirements, and revenue effects.

Task 5. Prepare and submit an interim report documenting the results of Tasks 1 through 4 within 9 months of project initiation. The interim report shall include an updated working plan for the remainder of the project. The researchers should also be prepared to brief the NCHRP project panel in Washington, D.C., within 10 months of contract initiation. NCHRP approval is required before proceeding with Phase II.

Phase II

Task 6. Using the Task 4 criteria, evaluate and, to the extent possible, quantify the consequences of the various alternative financing methods, identified in Task 2, under the scenarios presented in Task 3. The results of this task must be presented in an appropriate form for use by public policymakers in different environments.

Task 7. Identify issues for future research.

Task 8. Prepare and submit a final research report, an executive summary, and an applications manual derived from Task 4 that could be used by others for evaluating methods subsequent to the completion of this project.

Phase I is complete and the Phase I interim report is available on loan. Phase II, now underway, will place emphasis on refining the framework for evaluating various financing schemes. Realistic scenarios will be used for demonstrating the framework. Recognizing the varying circumstances that can exist throughout the country, the major product of this research will be the framework not the ideal financing mechanism, although a great deal of insight will be presented on the mechanism.

Project 20-24(8) FY '93

Project 20-24 Series—Revisited

Research Agency: Apogee Research, Inc.
Principal Invest.: Dr. Richard R. Mudge, John A. Clements, and Robert E. Farris
Effective Date: June 1, 1992
Completion Date: August 24, 1992
Funds: $20,000

In May 1992, Project Panel 20-24 met to select new projects for the "20-24 series." However, in the discussions about possible topics, questions arose about the series' success and appropriate future direction. Although believed to be successful based on anecdotal information, the panel concluded that it was time to check with the intended audience, i.e., the chief administrative officer (CAO) of state transportation departments. Accordingly, the objective of this project was to provide an assessment of (1) the impact of past and ongoing projects within the NCHRP Project 20-24 series on chief administrative officers, specifically, and other top managers of state departments of transportation, (2) the desirability of a research program for chief administrative officers and top managers, and (3), if desired, the issues that would benefit from research. The study is complete; an agency report is available for loan on request. Major conclusions from the study regarding completed work and proposed new research areas are as follows:

Evaluation of Previous Research; • Awareness of the research projects needs to be raised among CAOs; results need to be presented in a higher profile manner. • The formats in which the research projects are presented need to be more accessible to CAOs with busy schedules; the research must be more "user-friendly." • The research needs to present upfront what it can do for CAOs in their policy formulation; the ideas need to be "sold" to CAOs before they can be implemented.

Proposed Research Topics: • Environmental Consensus Building • Project Development • Privatization Options • State DOT Relationships with Other Governmental Units • Decentralization and Organizational Change • Management Support for Chief Administrative Officers • Effective Communication to Chief Administrative Officers • Strategic Investment Analysis: Choosing Among Competing Needs • Manager Training and Retention • Effectiveness of Incentive Systems • Civil Service Regulations

Project 20-24(9) FY '93

State Departments of Transportation—Strategies for Change

Research Agency: National Academy of Public Administration
Principal Invest.: Dr. Thomas Larson
Effective Date: June 15, 1993
Completion Date: December 14, 1994
Funds: $279,855

State departments of transportation (DOTs) are continually evolving because of planned and unplanned reactions to internal and external influences. Recently, however, the pace of this evolutionary process has greatly accelerated, so much so, that many state DOTs must rethink traditional ways of doing business. Influences contributing to this evolution include economic and demographic changes, variations in service and use demands, legislative edicts, rehabilitation needs versus new construction, modal integration, and elective and mandated changes in relationships with other governmental agencies and private organizations.

Specifically, requirements in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the Clean Air Act Amendments (CAAA) of 1990 have accelerated changes in state DOTs and created more challenges to their operations and functions. A few examples of initiatives in response to these Acts are a renewed interest in transportation planning, which includes a requirement for statewide planning and the consideration of the interrelationships and trade-offs among the various modes; increased public involvement; more stringent air quality requirements; increased flexibility in the use of federal-aid transportation funds; and better cooperation among DOTs, metropolitan planning organizations (MPOs), other state agencies, and transportation providers, particularly transit agencies. In addition, the CAAA and various energy considerations may force the use of alternative fuels and less gasoline consumption, jeopardizing the reliability of the gasoline tax (state and federal) as a major source of revenue. This fuel issue and other factors will require DOTs to explore alternative financing mechanisms, such as privatization, toll roads, revolving loan funds, assessments on transportation benefits, and other types of taxes or user fees.

Moreover, ISTEA has raised the expectations and the responsibilities of state DOTs. However, in many instances, these expectations and responsibilities are accompanied by reductions in staff to comply with across-the-board cuts in state governments, resulting in DOTs trying to do more with less. At the same time, ISTEA has raised the expectations and increased the responsibilities of other governmental and private organizations. Because of ISTEA's increased flexibility in the use of funds, many organizations now see the possibility for accessing these funds and sharing in decision-making responsibilities.

DOTs will have to respond to the various challenges

principally by redeploying available resources (e.g., personnel, inventories, and funds), applying new technologies, and implementing innovative approaches to management. For example, the application of Total Quality Management (or perhaps, better said, Continuous Quality Improvement) has the potential of producing flatter management structures (i.e., fewer layers) and more employee involvement. New technology may increase the span of management control, which also contributes to flatter management structures, by providing access to greater amounts of timely information. Unfortunately, the ability of DOTs to respond appropriately is often constrained by inadequate understanding of events, prescriptive state legislative requirements and personnel regulations, or reluctance to change by some civil servants.

These issues need to be addressed, and significant changes to the activities and organizational structure of state DOTs may have to occur. Guidance for planning a logical transition into the state DOT of the future will help to identify the critical organizational, institutional, and staffing issues facing DOTs and will facilitate independent state efforts, including interaction with state legislators. Guidance is also needed for defining the potential problems related to these issues and for developing possible remedies. The pace of change will continue to accelerate, and state DOTs must be prepared to react. Consequently, research is needed to ensure that DOTs will be prepared to continue to provide a fully integrated transportation system that is multimodal, safe, energy-efficient, environmentally sound, and cost-effective.

The objectives of this research are to (1) evaluate current and potential influences that affect the future of state DOTs, (2) describe and discuss the impacts on DOTs, (3) provide guidance for DOTs to assess their ability to respond, and (4) recommend solutions or techniques that will assist in the transition of DOTs to meet current and future challenges.

The accomplishment of these objectives will require the following tasks: (1) Identify and evaluate the most significant current and potential influences that will affect the mission, responsibilities, organizational structure, staffing, and institutional arrangements of state DOTs. (2) Describe the potential impacts of each of the items identified in Task 1 on state DOTs, recognizing the differences among states. Prepare an interim report on Tasks 1 and 2, which describes the effort and results, for review by the NCHRP. The researchers also shall make an oral presentation and interact directly with the NCHRP before proceeding with the remaining tasks. (3) Develop guidance for state DOTs to assess their ability to react to the impacts described in Task 2. This guidance shall be specific to existing functional areas (e.g., finance, engineering, and construction) and shall assist in identifying the need for new functions. The guidance must take into account such factors as department size and responsibilities, regional location, and state demographics. (4) Identify and discuss options by which state DOTs can make required changes based on the Task 3 assessment of capabilities. Recommend actions to respond to assessed shortcomings. (5) Prepare the final report documenting the research effort. Because a significant audience for the research results will be top officials of state DOTs, the guidelines in this report should provide them with (a) an understanding of the issues, (b) methods for assessing a DOT's ability to respond to change, (c) potentially appropriate actions to initiate, and (d) measures for judging success. Effective communications techniques should be used as appropriate to facilitate the understanding and application of the research results.

Tasks I and 2 are nearing completion. The agency has made an extensive number of contacts through general surveys as well as personal interviews to gain insight on the issues facing state DOTs.

Project 20-24(10) FY '94

Customer-Based Quality in Transportation

Research Agency: Howard/Stein-Hudson
Principal Invest.:
Effective Date: (12 months)
Completion Date:
Funds: $100,000

The American Association of State Highway and Transportation Officials (AASHTO) and its member departments are committed to continually improving the quality of their organizations and activities—a process often referred to as Total Quality Management (TQM). For example, AASHTO, along with the Federal Highway Administration and industry representatives, has become party to a National Quality Initiative and signed a National Policy on the Quality of Highways.

Many organizational efforts on quality begin with concerns about products and employees. However, in recent years, American businesses have been more successful when they took a broader approach and focused on "customer-based" quality. Quality achievements in products and by employees are necessary and commendable, but a quality-oriented program must be firmly grounded in "customer-based" quality.

All efforts to improve product development and employee performance could fail unless there is a clear understanding of the needs, desires, and expectations of the customer. Therefore, research should be undertaken to determine the following: (1) what the "transportation customer" needs, desires, and expects; (2) the components and indicators of quality as discerned by the customer; (3) transportation program objectives and performance measures for the movement of both people and goods; and (4) strategies for improving product development and employee efforts.

This effort can be accomplished by developing a program that uses "focus groups" in several states. These groups would be comprised of the beneficiaries of transportation (transportation meaning the movement of people and goods) from a cross section of geographic areas and socioeconomic levels. This approach, while not producing statistically valid

data for direct application in all states, will establish clear benchmarks for any "customer-based" quality program.

Project 20-25 FY '89

Training Needs for Highway Construction Personnel

Research Agency: University of Maryland
Principal Invest.: Dr. Everett C. Carter
Effective Date: June 15, 1989
Completion Date: December 31, 1990
Funds: $73,728

There is a continuing need to improve the management of the quality of highway construction and to reduce life cycle costs. Budget restrictions, loss of skilled personnel, increased responsibility placed on quality assurance personnel, changing role of the contractor in the area of quality control, and demands to construct projects faster have all affected the highway construction process in the United States.

An approach for meeting this need is improved training programs for field and office personnel at the highway construction site. Current training programs for these personnel are not comprehensive, are localized in their application, and lack national acceptance. A national training program for highway agency, consultant, and contractor personnel will respond to this need.

The ultimate goal of this research is the development of a nationally acceptable training program that specifically supports certification for agency, consultant, and contractor personnel involved in highway construction. The objective of this project is to provide a needs assessment and design a framework for a training program to improve the quality of highway construction.

Research on the first phase of the project has been completed, and the final report was reviewed. The agency report has been distributed to Program sponsors and other interested persons. It will not be published in the regular NCHRP report series, but loan copies are available upon written request to the NCHRP. See NCHRP Project 20-25(2) for the next phase to follow in this area to develop a comprehensive training program that will lead to nationally accepted certification based on the results of this project.

Project 20-25(2) FY '89

Training for Highway Construction Personnel

Research Agency: SNI Training Service, Inc.
Principal Invest.: Kramer Metz
Effective Date: November 1, 1991
Completion Date: May 31, 1994
Funds: $224,790

There is a continuing need to improve the management of the quality of highway construction and to reduce life cycle costs. Budget restrictions, loss of skilled personnel, increased responsibility placed on quality assurance personnel, the changing role of the contractor in the area of quality control, and demands to construct projects faster have all affected the highway construction process in the United States.

Improved training for field and office personnel at the highway construction site is an effective approach to meeting this need. Current training programs for these personnel are not comprehensive and are localized in their application; a national training program is needed for highway-agency, consultant, and contractor personnel.

An initial phase of research under NCHRP Project 20-25, "Training Needs for Highway Construction Personnel," developed a framework for a nationally applicable training program and produced a listing of courses as well as a list of job activities accomplished by construction personnel. This framework can be used to support certification, through the National Institute for Certification of Engineering Technicians (NICET) or other job-task competency certification systems. Certification for the purposes of this project implies that an individual has demonstrated the knowledge of identified job requirements and has demonstrated ability to perform identified activities with proficiency gained by repeated involvement in each activity.

The objective of this second phase of research is to prepare a training program and a plan for its use by highway agencies, consultants, and contractors, based on the framework developed under NCHRP Project 20-25. This program will provide the basis for training that will improve the quality of highway construction, will support certification of construction personnel, and will be responsive to the cultural diversity of a changing work force that is expected to be increasingly made up of minorities and women. The program shall be designed to train supervisors, foremen, and inspectors.

Accomplishment of this objective will require, as a minimum, the following tasks:

Task 1. Survey and evaluate existing training resources and materials relating to the courses outlined in Appendix E of the Final Report of NCHRP Project 20-25. These resources shall include, but not be limited to, lesson plans, course outlines, student workbooks, visual aids, slides, videos, and other training materials. The evaluation shall consider the technical accuracy and applicability of these resources to the listed training courses. All materials reviewed will be listed. Those deemed of value shall be separately cataloged for each course with a listing of the source, description, applicability, and availability. All data and training materials accumulated during the progress of this project will be delivered to NCHRP at the conclusion of the project.

Task 2. Develop a course description and lesson-plan outline containing at least the elements listed below for each of the 62 courses in Appendix E of the Final Report from NCHRP Project 20-25. These course descriptions and les-

son-plan outlines will form the basis for comprehensive training packages, some of which will be developed in Task 3. Proposed formats for the course descriptions and lesson-plan outlines shall be part of the proposal.

Course descriptions would include at least the following: title and number from Appendix E, scope statement, objective, target audience, overall course length (in hours), and instructor qualifications.

Lesson-plan outlines will include at least the following: outline identifying all important points to be covered in the course, time to be devoted to major subdivisions, identification of the appropriate media and required training aids, logistical support required, and references, training aids, and other instructor materials cataloged in Task 1.

Task 3. Develop complete training packages for the courses listed below. The packages should be complete enough to teach the course, and capable of being modified slightly, if necessary, to reflect specific state practices.

The courses are: GEN-4 Daily Diaries, GEN-9 Environmental Protection Procedures, and STR-2 Bridges.

The training package shall include at least the following: instructor materials (macro outline (1 page), detailed lesson plan, audio-visual aids (including videos), and other training aids—charts, graphs, maps, etc.); student materials (workbooks, practice exercises, handouts, and reference material); and evaluation materials (of student, of course, and of instructor).

Task 4. Develop a plan for promoting and facilitating the use of the recommended training program for highway agency, consultant, and contractor highway construction personnel.

Task 5. Prepare a final report on the total research effort.

Research on Tasks 1 through 3 has been completed, and work is proceeding on Tasks 4 and 5 on schedule.

Project 20-26 FY '89

Bond and Insurance Coverages for Highway Construction Contractors

Research Agency: Texas Transportation Institute
Principal Invest.: Dr. Donn Hancher
Effective Date: June 1, 1989
Completion Date: September 30, 1990
Funds: $99,999

The objectives of this research were to identify, analyze, and prioritize factors that affect the cost and availability of bonds and insurance on public highway construction contracts. The research provides an analysis of factors such as design and construction practices, contractor safety records, size and type of projects, environmental issues, legal climates, OSHA requirements, quality control, state and federal laws, and a number of other similar issues.

Research has been completed and the final report published as NCHRP Report 341, "Bond and Insurance Coverages for Highway Construction Contractors." The report provides a detailed examination and prioritization of these factors along with recommendations for actions that may relieve cost and availability problems. The recommendations apply to state, federal and local highway agencies, highway construction contractors, and the insurance and bonding industries.

Project 20-27 FY '90

Adaptation of Geographic Information Systems for Transportation

Research Agency: University of Wisconsin
Principal Invest.: Dr. Alan Vanderohe
Effective Date: March 1, 1990
Completion Date: June 30, 1993
Funds: $220,000

Administrators, engineers, and researchers are continually faced with transportation problems on which much information exists, often in the form of reports, computer data, and undocumented experience and practice. Because of the complexity of many transportation issues, both within and across modes, the information required to fully consider the various alternatives frequently resides in a number of units within local, state, and federal agencies and is not readily available for use in the decision process.

Geographic information systems (GIS), which have been successfully applied in many fields outside of the transportation industry, offer the potential to assemble and process data from a diversity of sources and present it in an easily understood graphical format. A GIS is a computerized data management system that is designed to capture, store, retrieve, analyze, and display spatially referenced data. The capabilities of a GIS in the transportation field, hereinafter referred to as GIS-T, will permit the assimilation, integration, and presentation of data collected and stored by each of the divisions within a highway agency. Additionally, it can accommodate information gathered and stored by other agencies.

To exploit the full capabilities of GIS-T, there is a need to identify current applications of GIS concepts and technologies in the transportation field, to identify transportation problems that can not be addressed by current GIS concepts and technologies and thus will require the development of new or extensions to existing concepts and technologies, to design a GIS-T that will provide comprehensive and timely information for management decision support, and to assess the impacts of implementing a GIS-T on the transportation industry.

The objectives of this research project are to: (1) identify and evaluate the state of practice and planned activities in GIS-T, (2) identify transportation problems requiring new capabilities or extensions to currect GIS concepts and technologies, (3) design a GIS-T based on current and anticipated

transportation agencies' needs, and (4) assess the impact of implementing the designed GIS-T on the transportation industry.

This research shall include at least the following tasks:

Task 1. Identify and assess current and planned activities in the design, development, implementation, and operation of GIS-T. Information gathered from transportation agencies, other agencies with data of interest to transportation agencies, and vendors of GIS and GIS-T products should include but not be limited to:

- GIS and GIS-T concepts and technologies; definitions of GIS-T; GIS-T structures; internal and external system components and relationships; analytical tools; standardization issues; data collection, conversion, and maintenance; map scales; location reference methods; accuracy/precision issues; use of expert systems; system outputs.
- Areas of application (e.g., accident analysis, hazardous material routing, highway performance monitoring systems, planning, project management, socioeconomic and environmental impact).
- Internal and external agency coordination; shared data (e.g., census, geological, land use, value and zoning, local traffic engineering and planning, utilities).
- Management support and involvement; training; institutional issues; procurement issues; copyrighting and licensing issues; costs and benefits.

Task 2. Based on the results of Task 1, design an idealized framework(s) for a GIS-T. The framework(s) should include each of the appropriate system characteristics identified in Task 1 and any other characteristics the researchers deem to be advantageous. The framework(s) developed should use modular component design to facilitate staged development and be independent of the computing environment. Within this task the researchers shall also identify transportation problems that will require the development of new or modified GIS and GIS-T concepts and technologies.

Task 3. Prepare an interim report documenting the research completed in Tasks 1 and 2. Soon after submission of the interim report for review by the NCHRP project panel, a meeting between the research team and the NCHRP project panel will be scheduled for the purpose of providing panel members the opportunity to interact with the researchers in a detailed discussion of the contents of the interim report. NCHRP approval of the interim report will be required before proceeding with Task 4.

Task 4. Design a GIS-T(s) based on the panel approved framework(s) in Task 3. The GIS-T(s) design shall contain sufficient detail to allow for the development of a GIS-T. For transportation problems that will require the development of new or modified GIS and GIS-T concepts and technologies, the researchers shall provide a detailed description of the problems and a brief description of potential concepts and technologies required to address these problems.

Task 5. Identify GIS-T inplementation issues and how the introduction of GIS-T will potentially change the transportation industry. Based on the results of this effort prepare a management guide to assist transportation agencies in the implementation of a GIS-T.

Task 6. Prepare 5- and 10-year forecasts of the potential applications of GIS-T. These forecasts shall address planned and anticipated advances in technology, how these advances will be applied, and their impact on the transportation industry. Within these forecasts the researchers shall also identify basic and applied research efforts needed to support GIS-T development during the forecast periods.

Task 7. Prepare a final report documenting the research effort.

The final report has been published as NCHRP Report 359. The Management Guide has been published as Research Results Digest 191.

Project 20-28 FY '90

Hazardous Wastes in Highway Rights-of-Way

Research Agency:	Transportation Research Board
Principal Invest.:	Robert E. Skinner, Jr. Mark R. Dayton
Effective Date:	April 16, 1990
Completion Date:	September 30, 1993
Funds:	$300,000

Whether involved with a new highway project or the improvement of an existing project, state departments of transportation are encountering hazardous waste sites in highway rights-of-way with increasing frequency. Although more and more states have gained considerable experience on a case-by-case basis and a few have developed overall programs, state transportation officials can still benefit from better awareness of the regulatory and technical issues and from improvements to overall programs for dealing with expected or unexpected discovery of hazardous waste during land acquisition, project development, and construction.

Because of the possible policy implications, the project was assigned to the Special Studies Division of the Transportation Research Board. This Special Studies Division performs transportation policy studies as a unit of the National Research Council (NRC). Accordingly, an NRC study committee was assembled that included experts in highway design and construction, hazardous waste remediation, environmental law, environmental health, and public policy. The committee was charged with developing the recommended guidance by building on past NCHRP research—the results of which were published in NCHRP Report 310, "Dealing with Hazardous Waste Sites"—and on material from the Federal Highway Administration's National Highway Institute.

The study was conducted by examining a number of case studies of problems encountered by state departments of

transportation. Drawing on these findings and the experience and expertise of its members, the committee has provided guidance to state transportation officials on managing hazardous waste-site problems. The final committee report has been published as NCHRP Report 351, "Hazardous Wastes in Highway Rights-of-Way."

Appendix B, "State Documents That Describe Hazardous Waste Policies and Procedures," comprises some 970 pages and is not published in the NCHRP report. Copies of Appendix B were distributed to all NCHRP sponsors along with the published report. Others may obtain copies of Appendix B on loan or for purchase.

Project 20-29 FY '92

Development of a Multimodal Framework for Freight Transportation Investment: Consideration of Rail and Highway Trade-offs

Research Agency: Texas Transportation Institute
Principal Invest.: Dr. Steve Roop
Effective Date: May 15, 1992
Completion Date: August 31, 1994
Funds: $150,000

Transportation systems and policy in the United States have developed along modal lines with different patterns of ownership. For example, public agencies plan, build, operate and maintain the highway infrastructure, and private firms plan, build, operate, and maintain rail lines. While there have been some variations on this pattern with the construction of private toll roads and the investment of public funds in rail planning and rehabilitation, public planning and investment decisions are usually made independently by mode. The negative effects of this dichotomy have become apparent, for example, when rail lines are abandoned. With few exceptions, federal and state highway trust funds are invested strictly in roads not rail. Similarly, rail funds under the Local Rail Freight Assistance (LRFA) Act and similar state programs may be used for substitute service, but they are rarely, if ever, invested in highways. Modally oriented planning and investment have been shown to be economically inefficient and generate fewer social benefits than might be achieved under a multimodal approach. For example, research has indicated that the abandonment of rail lines with the diversion of traffic from rail to truck, can significantly increase highway infrastructure costs. Thus, the investment of public funds in rail branch lines can not only generate shipper benefits but also reduce future highway and bridge costs.

The objectives of this research are to develop a framework for efficient and effective multimodal investment practices, demonstrate the viability and applicability of the framework, identify obstacles to implementation at the state and local levels, and develop strategies for successfully implementing improved practices. The research will evaluate varied examples of transportation investment trade-offs, focusing on rail-highway trade-offs in state rail program activities.

In order to achieve the objectives of the project, the following tasks are envisioned. Task 1—Identify sound multimodal transportation investment practices, both domestic and foreign, which have relevance in the United States. Task 2—Identify and describe areas of suboptimization and inefficiency in existing U.S. multimodal transportation investment practices. Discuss the impacts of investment decisions and their outcomes from regional, state, local and/or national perspectives. Task 3—Drawing from economic theory and current practices define an efficient and effective framework for transportation investment. Identify the organizational, institutional, and political elements in the U.S. that might limit the use of such a framework in multimodal situations. Identify those factors that are appropriate for inclusion in the framework (e.g., pavement damage, transportation costs, direct and indirect economic impacts, energy use, productivity, air quality, and safety impacts). Task 4—Prepare an interim report documenting the findings of Tasks 1, 2 and 3 and describing the framework developed. Recommend a varied set of case studies of highway-rail investment trade-offs that would be analyzed to demonstrate the application of the framework. Meet with the project panel to discuss the framework and the recommended case studies. Revise the framework in accordance with the panel's comments. Task 5—Analyze the case studies approved by the panel in the context of the framework defined in Task 2 to assess the potential trade-offs for investment of public funds in addressing highway and rail line needs. Compare these results to those previously derived in terms of the social costs and benefits associated with actual or potential rail line abandonments. Task 6—Describe the steps required to implement the framework within a state agency to improve multimodal investment decision-making. Identify the policy and organizational changes that are needed to implement the framework. Task 7—Prepare a final report fully documenting the research effort and findings. The final report shall also include, as an appendix, a synoptic version of the framework and implementation recommendations which can be directed toward decision-makers.

The panel tentatively approved the analysis framework at the interim meeting, but requested clarifications in a revised interim report.

Project 20-30 FY '92 and continuing

NCHRP-IDEA

Research Agency: Transportation Research Board
Principal Invest.: Kuppusamy Thirumalai
Effective Date: July 8, 1992
Completion Date: Continuing
Funds: $500,000 FY '92
$1,000,000 FY '93
$1,000,000 FY '94

This project represents a new approach under the National Cooperative Highway Research Program called the NCHRP-IDEA (Innovations Deserving Exploratory Analysis) for short-term focused research on new and innovative concepts, which have the potential to provide leapfrog technological advances. Funds will be received from FHWA to partially support this Project.

Actually, NCHRP-IDEA is a continuation of the successful and highly visible SHRP-IDEA program that is providing important innovative concepts from the public and private sectors in the areas in which SHRP research is concentrated. The SHRP Program ends in March 1993. However, due to the success of the IDEA program, there was significant interest in its continuation, and a consensus has developed that this should take place under the NCHRP Program. Unsolicited proposals will be accepted that are related to any aspect of highways or intermodal facilities; however, the Project Committee will designate specific technological areas for emphasis.

NCHRP-IDEA will be handled as a project under each Fiscal Year NCHRP Program, similar to the NCHRP Synthesis Program (Project 20-6). NCHRP will contract with TRB Special Programs Division for the accomplishment of the project, and they in turn will establish staff positions to administer and contract specific research investigations. Investigations will be selected by a NRC-appointed NCHRP Project Committee. The project is anticipated to be funded at the level of $1,000,000 per year, which would allow six or seven contracts for innovative research each year. FHWA has agreed to provide 75% of the funding, with AASHTO providing the remainder. The AASHTO Standing Committee on Research (SCOR), at its September 4–5, 1991, meeting, approved an allocation totalling $375,000 (FY '92 transition year at $125,000 [half-year], and FY '93 at $250,000). The FY '92 funds have been matched by the half-year amount from FHWA of $375,000. The recommended allocation for FY '94 of $250,000 was approved by SCOR at its meeting on September 9–10, 1992. It is anticipated that FHWA will participate in FY '93 and FY '94 with $750,000 in each year.

All final reports from NCHRP-IDEA investigations will be disseminated to all state highway agencies. In addition, an annual summary of progress in each designated technology area will be prepared and distributed.

The NCHRP-IDEA Project has been initiated, and the Project Committee of 12 individuals has been formed to oversee the activity. At its initial meeting on July 8, 1992, the Committee adopted operating procedures, designated four technology areas, and made decisions on funding specific proposals carried over from the SHRP-IDEA program. The initial Project Announcement has been distributed, and 150 concept proposals (3-page proposals) have been received.

An initial screening of these submittals by the project committee has been completed. Forty successful candidates have been requested to submit a detailed proposal (in-depth proposal). These detailed proposals will be reviewed by Technical Review Panels in November 1993. A meeting of the NCHRP-IDEA Project Committee will be held in December 1993 to discuss the operation and decide on projects to fund. It is anticipated that up to 15 new NCHRP-IDEA investigations will be funded with the funds allocated by SCOR and anticipated from FHWA.

It is also anticipated that up to 15 NCHRP-IDEA investigations will be funded each year.

This Project will continue to allow pursuit of innovative concepts in the technology areas selected by the Project Committee. Solicitations for proposals will proceed as directed by the Committee.

Project 20-31 FY '93 and FY '94

Public Policy for Surface Freight Transportation

Research Agency:	Transportation Research Board
Principal Invest.:	Robert E. Skinner, Jr. and Joseph R. Morris
Effective Date:	December 1, 1992
Completion Date:	March 30, 1995
Funds:	$175,000

The multimodal U.S. freight transportation system (rail, truck, barge, and pipelines) is privately operated, but government has influenced its development and operation through the provision of infrastructure and support services, taxation, and economic and safety regulations. Because of inherent differences among modes and because the modes developed in different time periods, government policies are often inconsistent across modes, potentially providing subsidies to some modes, adding unnecessary costs to others, and thereby distorting the competitive balance. These inconsistencies—coupled with opportunities for greater efficiency, new technologies, and public infrastructure financing needs—have resulted in a steady stream of proposals for incremental changes to existing policies affecting freight transportation. Examples include changes in truck size and weight limits, highway and waterway taxes, and railroad labor laws.

Ideally, decisions about these proposals should be made with knowledge about (1) the extent to which current policies foster efficient use of the freight system; and (2) the extent to which current use by mode differs from the use that would be expected if no public subsidies were provided and each mode were responsible for any external costs (such as air pollution) it imposed on the public at large. Such knowledge about subsidies and external costs does not exist, and providing it would be a formidable undertaking given the conceptual and practical difficulties involved.

As a first step, TRB has convened a committee to explore the potential usefulness and feasibility of a comprehensive baseline study of freight transportation to measure subsidies and external costs and to assess their consequences for the amount of freight traffic and the distribution of freight among

modes. The committee includes experts in economics, freight transportation, transportation regulation and policy, and transportation data and statistics. The study tasks being undertaken by the committee include:

- Recommending an appropriate economic analysis framework and explaining its relevance to policy problems;
- Inventorying data and methods that would be needed for the analysis, identifying gaps, and determining the activities needed to fill these gaps;
- Roughly assessing the scale of subsidies and external costs involved to help determine the feasibility and approach of a more detailed and comprehensive analysis;
- Determining if the analysis could be performed in phases or usefully disaggregated to critical market segments where two or more modes compete;
- Detailing the technical approach, data requirements, and resource requirements for a comprehensive analysis or components thereof that are recommended; and
- Preparing a report containing an assessment of the feasibility of a comprehensive economic analysis of freight transportation subsidies and external costs; preliminary estimates of the scale of subsidies and external costs; and, if warranted, recommendations about the technical approach and tasks that should comprise a comprehensive analysis.

Thus far the committee has prepared a series of literature reviews on the state of the art in estimating the various categories of cost and subsidy and freight market response to changes in user fees or other costs. Initial estimates of subsidies and external costs for actual freight corridors or freight movements will be determined through case studies, rather than by directly estimating aggregate nationwide costs. This approach will ensure inclusion of critical local or industry-specific effects that might be overlooked in a more aggregate analysis, such as the importance of local conditions in urban areas in determining the magnitudes of environmental and congestion costs.

The objectives of the corridor analysis will be to test techniques for estimating external costs and subsidies and market responses to changes in user fees and costs, and to identify the critical parameters and main sources of uncertainties. In addition, the results might have some general validity and relevance to policy issues; although care would be needed to avoid invalid generalizations arising from selection of unrepresentative case studies.

Each case study will be a specified category of commodities shipped between a specified origin and destination. Data will be assembled for each case study about routes, congestion along the routes, population density, public infrastructure conditions, accident rates, air quality, logistical and modal options for the shipment, and other factors that relate to the cost of the freight movement and to shipper and carrier choices.

The costs to be estimated include the public sector costs for serving the shipments on public roads or waterways, net government user fee revenues from the shipments; environmental costs, including air pollution and noise; accident costs not borne by the shipper or carrier; congestion costs; and external costs of energy consumption. In addition, consideration will be given to government-imposed costs for regulatory compliance. Finally, projections will be made of market responses to changes in user fees to cancel external costs or subsidies. Costs for alternative modes will be estimated.

Project 20-32 FY '94

Development of a Comprehensive Thesaurus for Transportation Research

Research Agency: CDB Enterprises, Inc.
Principal Invest.: C. David Batty
Effective Date: November 1, 1993
Completion Date: May 30, 1995
Funds: $225,000

Tremendous volumes of information are currently being generated on the planning, design, operation, maintenance, and administration of transportation systems in the United States and abroad. This information, which ranges from specific engineering data to research summaries, is regularly used by federal and state agencies, universities, and other organizations. Storage and retrieval systems have been created to manage and provide access to this information.

Retrieval of information on a specific subject is based on language. If the vocabularies of those who assign indexing terms and those who seek the information vary, searchers will miss needed items and retrieve unwanted information. For example, searching for the word "plants" may yield results on both vegetation and industrial facilities. The entry term "transitways" alone may not provide information on "high occupancy vehicle lanes." Searches are further complicated by local practices that dictate the use of alternate terminology. For example, "guardrail" is the commonly used term for a type of roadside barrier, but some states use the term "guiderail." Such difficulties are inherent in a language-based system.

There will be many applications for a transportation thesaurus. A primary use will be to provide a common language between producers and users of the Transportation Research Information Service (TRIS). The thesaurus will also have potential for indexing the Highway Technology Information Management System of the Federal Highway Administration (FHWA) and in organizing various statistical compilations to be developed by the Bureau of Transportation Statistics. American Association of State Highway and Transportation Officials (AASHTO) member departments will be able to use the vocabulary to organize collections of reports, slides, and video tapes as well as to build databases of projects and

product evaluations. Further benefits will be realized by TRIS indexers through the use of consistent terminology. Ultimately, engineers, planners and all of those involved in transportation research and its application will have better access to technical information.

The objective of this research is to develop a comprehensive thesaurus of transportation terminology to enhance information storage and retrieval. The thesaurus, which will cover all modes and aspects of transportation, will be reviewed by the project panel and other professionals to ensure adequacy of its scope and content. The project will also recommend procedures for thesaurus maintenance.

In order to accomplish the objective, the following tasks are envisioned:

Task 1. Assemble a set of candidate terms. The core list of terms will be the descriptors currently used in the Transportation Research Information Service (TRIS), which includes approximately 20,000 terms.

Task 2. Develop a list of broad subject categories (i.e., top terms) that will serve as the logical framework for the organization of the thesaurus. The contractor will document the results of this task in a working paper to be reviewed in a meeting with the panel.

Task 3. Construct the thesaurus in accordance with the NISO standard. This task will include selecting preferred terms, specifying the form of terms, assigning terms to categories, developing hierarchical relationships among terms, creating cross-references, and adding descriptive or scope notes where needed. It will also include checking the hierarchies and the relationships of terms for logical consistency.

Task 4. Generate a draft computer file and a draft of the printed thesaurus for review and testing. Printed versions will be generated in the following formats: (a) alphabetical, (b) permuted, and (c) hierarchical.

Task 5. Recommend a process for maintaining the thesaurus, and provide a procedures manual. Maintenance includes reviewing, revising, and updating the terminology based on input from internal and external sources. Define technical, staffing, financial, institutional, and other requirements to assure effective maintenance.

Task 6. Submit the products of Tasks 4 and 5 to the project panel for review. Revise these products based on the panel's comments. Prepare 100 copies of the revised materials and distribute them for further review to a list (provided by NCHRP) of transportation and information management professionals. The NCHRP will assemble the review comments and compile a summary. The contractor will recommend changes to the thesaurus in response to these comments. The contractor will meet with the panel to review these changes and determine which ones will be incorporated in the final versions of the materials.

Task 7. Generate a final version of the printed thesaurus, procedures manual, computer file, and file documentation. Deliver 100 copies of all materials to the NCHRP.

Task 8. Prepare a final report that documents the entire research effort.

Project 20-33 FY '94

Facilitating the Implementation of Research Findings

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (24 Months)
Completion Date:
Funds: $500,000

Great promise and risk are inherent in the large increases in research spending called for in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. The underlying expectation is that "research pays off" by yielding innovative products and practices that will benefit future transportation users and providers. Over the next several years, that expectation will be tested as a large volume of research results is reported from the FHWA's contract research programs, the Strategic Highway Research Program, the NCHRP, and newer programs authorized by the ISTEA.

"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." So said *America's Highways: Accelerating the Search for Innovation* (*TRB Special Report 202*, 1984), which laid the groundwork for the Strategic Highway Research Program. Add to the above list the extremely decentralized nature of transportation decision making in the United States, and the extent of the challenge is clear. Especially in the public sector, the barriers to implementation of research findings have been both institutional (many agencies/levels of government) and organizational (a risk-averse public management culture).

To improve technology transfer and facilitate the implementation of research findings in surface transportation, the significant factors that influence the implementation of research findings must be recognized and addressed, the characteristics of organizations that have succeeded in being innovative must be identified, and strategies for creation of an environment conducive to innovation and timely application of research findings must be developed and applied.

The objectives of this research are to (1) identify and evaluate the significant factors that influence the implementation of research findings, (2) determine ways to improve technology transfer and facilitate interagency and public-private cooperation in applying research results in surface transportation, and (3) recommend strategies to create an environment conducive to innovation and timely application of research findings in surface transportation. To accomplish these objectives, the following two research phases will be conducted:

Phase I: (1) Compile a summary of the current public and private implementation practices. Also, develop a definition for research implementation. The different types or classes of research products, potential users, technology-dissemination methods, and other contributing factors shall be identified and considered in all research tasks. (2) Evaluate the practices identified in Task 1 and define those factors that encourage or discourage the implementation of research findings. These factors should include, but not be limited to, corporate culture, finance, politics, legal aspects, risk, and presence or absence of champions for change. (3) Identify and compile a comprehensive list of research studies that should be pursued to help achieve the project objectives. For each identified study, provide a detailed problem statement that describes the need for the study, the research objectives and scope, and an estimate of funding and time requirements. Outline a strategy for sequencing these studies and recommend a priority ranking. Some of these research project statements will be considered by the NCHRP panel for funding in Phase II, and others will be considered by NCHRP and other organizations for future funding. To gain further insight into the issues and possible study approaches for this part of the research, interviews or workshops with experts from universities and the public and private sectors as well as representatives of the highway industry (e.g., government officials, industry association representatives, contractors, suppliers, equipment manufacturers) will be considered. (4) Prepare an interim report that (a) documents the research performed in Tasks 1 and 2, (b) compiles the research problem statements developed in Task 3, and (c) provides an updated work plan for the Phase II portion of the project describing rationale, methods, schedule, budget, and other required details. Following review of the interim report by the project panel, the research team will be required to make a presentation to the project panel. (5) Revise the work plan for Phase II based on the Task 4 panel review.

Phase II: (6) Execute the approved work plan prepared in Task 5. Proposers are expected to discuss their current thinking in sufficient detail to demonstrate their understanding of the problem and the soundness of their approach to developing practical solutions. (7) Prepare a final report that documents the entire research effort in accordance with NCHRP requirements. The report shall include practical recommendations that will help make possible the timely application of research findings. Following review and comment by the project panel, the research team will be expected to make a presentation on the project findings to the project panel.

Project 20-34 FY '94

Developing Measures of Effectiveness for Truck Weight Enforcement Activities

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (18 months)
Completion Date:
Funds: $250,000

Truck weight enforcement programs were initiated to limit the amount of damage to the infrastructure and to promote public safety. The level and value of truck weight enforcement activities are currently gauged by means of statistical measures such as the number of trucks weighed, the number of violators detected, and the amount of fines collected. Continuing to use such statistical measures may demonstrate level of effort, but will not indicate what is actually being accomplished as a result of that effort. A true measure of the effectiveness of truck weight enforcement programs would indicate what, if any, real effect is being achieved. Useful measures of effectiveness might, for example, quantify the reduction in the number, proportion, and severity of illegally overweight trucks. Thus, use of such measures of effectiveness will provide a meaningful way to quantify what is accomplished by weight enforcement efforts.

The objective of this research is to develop and validate measures of effectiveness for truck weight enforcement programs.

The research will include as a minimum the following tasks:

Task 1. Conduct a literature review and surveys to identify current and planned measures of effectiveness for truck weight enforcement programs. Particular attention will be paid to identifying measures of effectiveness, rather than levels of effort.

Task 2. Evaluate and rank the measures identified in Task 1.

Task 3. Propose measures of effectiveness (not limited to those identified in Tasks 1 and 2) that quantify what is achieved as a result of the effort; they should not merely gauge the effort (number of trucks weighed, number overweight, etc.). Apply the criteria used in Task 2 to evaluate the proposed measures of effectiveness. A necessary consideration in completing this task will be the identification of what data are required and how those data will be collected and processed to compute the measures. Guidance should also be provided for interpreting the measures.

Task 4. Within 6 months after initiation of the research, submit an interim report describing the results of Tasks 1 through 3 and presenting a work plan for the remainder of the project. The plan for Task 5 should include 20-34, page 2 proposed test methods, budget, timetable, and measures to be tested. NCHRP approval will be required before proceeding with subsequent tasks.

Task 5. Conduct a program to evaluate, refine, and validate the proposed measures.

Task 6. Devclop the final list of recommended measures of effectiveness and recommend guidelines for their use.

Task 7. Prepare a final report detailing the entire research effort.

Project 20-35 FY '94

Plan for SHRP Follow-Up Studies

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (12 Months)
Completion Date:
Funds: $100,000

The Strategic Highway Research Program (SHRP) was established by Congress in 1987 as a 5-year, $150 million research program to improve the performance and durability of our nation's roads and to make these roads safer for both motorists and highway workers. The research, performed by independent contractors, is targeted in four areas: highway operations, concrete and structures, asphalt, and long-term pavement performance (LTPP). The 1991 Intermodal Surface Transportation Efficiency Act authorized additional funds for SHRP implementation and continuation of the 20-year LTPP program. The Federal Highway Administration (FHWA), which is responsible for continuation of the LTPP program, is taking the lead in helping highway agencies make effective use of SHRP products.

As with any major research initiative, along with accomplishments, new needs and opportunities are emerging as SHRP nears completion. Indeed, SHRP staff and research contractors have already identified several topics for follow-up studies—in the areas of highway operations, concrete and structures, and asphalt—to help bridge the gap between research findings and implementation. As part of its responsibility for the continuation of the LTPP portion of SHRP, the FHWA will periodically address the needs for further research in pavement engineering.

Research is needed to identify and prioritize research and development activities related to highway operations, concrete and structures, and asphalt that should be pursued following the completion of SHRP to build on the completed research and to help facilitate the use of SHRP findings. To formulate a position on the needs for SHRP follow-up research and to identify the projects, the NCHRP expects to convene a workshop focused specifically on evaluating prospective research projects. In preparation for the workshops, the investigators selected to assist in NCHRP Project 20-35 will compile preliminary lists of potential research projects through review of SHRP findings and contact with individuals directly involved in the conduct, surveillance, and management of SHRP research and use of its findings. Following the workshop, the investigators will prepare three separate reports; each report will address the follow-up research needs for one of the SHRP research areas. These reports will reflect the workshop deliberations and indicate the priority ranking of the recommended research projects based on consensus of the participants.

The investigators selected to assist in NCHRP Project 20-35 will compile preliminary lists of potential research projects through review of SHRP findings and contact with individuals directly involved in the conduct, surveillance, and management of SHRP research and use of its findings.

Such individuals should be familiar with the many research activities conducted by SHRP, including those that were successfully completed and those that were curtailed because they did not appear promising. Staff; research contractors; advisory committees and panels of SHRP; and representatives of state, county, and local highway agencies and the highway industry are well suited for these contacts. The preliminary lists covering highway operations, concrete and structures, and asphalt should provide adequate details of the problem, the project objectives, potential benefit to highway agencies, and estimates of funds and time period required to perform the research. The NCHRP project panel in conjunction with the investigators will determine the format, scope, participants, and other details of the workshop. Following the workshop, the investigators will prepare three separate reports; each report will address the follow-up research needs for one of the SHRP research areas. These reports will reflect the workshop deliberations and indicate the priority ranking of the recommended research projects based on consensus of the participants.

Project 20-36 FY '94

Highway Research and Technology—International Information Sharing

Research Agency: NCHRP
Principal Invest.: Amir N. Hanna (NCHRP Staff Engineer)
Effective Date: 1/26/93
Completion Date: 4/30/94
Funds: $150,000

Highway authorities world-wide share many common concerns in the planning, design, construction, operation, and maintenance of highway systems. Most developed nations also support programs of research and development (R&D) on highway issues. The potential for information sharing and technology transfer is great. Coordination of research in the United States has focused primarily on technology transfer and information dissemination among the large and diverse community of state and local highway agencies within this country. Although there is a great need to improve highway practices at all levels, the United States does not have a systematic exchange mechanism to learn from counterparts abroad, where many new developments have been tested and successfully used for highways.

U.S. participation in international activities has been at a small scale and most often conducted on an ad hoc basis. For example, selected FHWA R&D program managers may attend international conferences addressing highway research issues. Similarly, researchers from other countries might participate in U.S. conferences, such as the Transportation Research Board (TRB) Annual Meeting; others have been "loaned" to U.S. R&D program offices, such as the

Strategic Highway Research Program (SHRP). U.S. research programs, such as the SHRP Long-Term Pavement Program, may extend their activities to include foreign partners.

FHWA has long been active in the Road Transport Research Program of the Organization of Economic Cooperation and Development (OECD) and has recently initiated increased cooperation with the Pan American Congress and become a full member of the Permanent International Association of Road Congresses (PIARC). TRB participates in information exchange with the International Road Research Documentation database. FHWA is examining alternatives for coordinating these and future international highway activities.

These issues should be addressed to develop and promote a more coordinated and systematic approach to international information exchange and technology sharing by FHWA, AASHTO, and other major users and producers of highway R&D. This activity should make it possible to have an international program that allows state participation and enhances the roles of AASHTO, TRB, and FHWA in providing coordinated leadership for the exchange of international highway research and development.

This project will provide a mechanism which will make it possible to have an international program that allows state participation. The project will include at least the following activities: (a) participation of U.S. members in PIARC committees to exchange and gather information applicable to U.S. conditions, (b) participation in international study tours to explore technologies of potential benefit to U.S. transportation systems, (c) exchange visits with foreign experts and professionals to learn about practices and technologies of potential benefit to state highway agencies, and (d) means to inform U.S. highway professionals about foreign developments that may apply to U.S. conditions.

Four individuals participated in the Joint Meeting of PIARC Committees and Working Groups, held in Yokohama, Japan, April 26-29, 1993, and subsequent PIARC committee meetings. Another individual participated in the Civil Engineering Research Foundation (CERF) International Task Force Trip to Western Europe, June 5-14, 1993. A German pavement expert was invited to participate in the AASHTO Annual Meeting to discuss German pavement technology and other new technologies in the European community.

Project 20-37 FY '94

Strategic Direction for the NCHRP and Other AASHTO Research Activities

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (12 months)
Completion Date:
Funds:

At its September 1992 meeting, the Standing Committee on Research (SCOR) of the American Association of State Highway and Transportation Officials (AASHTO) identified the need to examine AASHTO's research-related activities and, in particular, the National Cooperative Highway Research Program (NCHRP), administered by the Transportation Research Board. At that time, funds were approved to conduct a strategic analysis of SCOR and the NCHRP.

The NCHRP started in 1962 and, during its 30-year history, the program, although undergoing some evolution in technical content and procedures, has varied little from the original design. Faced with a new environment in the future [e.g., Intermodal Surface Transportation Efficiency Act (ISTEA) and other legislated requirements; major emphasis on the development and deployment of Intelligent Vehicle Highway Systems (IVHS); and the expiration of the Strategic Highway Research Program], SCOR decided that it would be timely to assess its activities and to develop a strategy for the future.

In March 1993, NCHRP Project Panel SP20-37 identified four strategic issues that need to be addressed to position SCOR and the NCHRP to fulfill their missions in the years ahead. These four issues are as follows:

1. The process for NCHRP program formulation needs to be examined. The Project Panel noted that much of the current program consists of unrelated projects approved on an annual basis. The program could benefit from long-term goals and more structured coordination with other research agencies.
2. Greater involvement by executive-level officials of the state DOTs is needed in AASHTO's research activities and particularly in establishing emphasis areas, priorities, and overall policy direction for the NCHRP. In many state DOTs, research is not viewed by executive management as an instrument for change.
3. An implementation strategy is needed for the NCHRP and other AASHTO-supported research activities. Research findings must be "user friendly" to ensure effective application of research products.
4. With the expansion of the NCHRP resulting from the increase in funds made available by ISTEA, it will be important to ensure that procedures, staffing, and other administrative concerns are cared for effectively to maintain the technical quality of NCHRP products.

AREA 21: TESTING AND INSTRUMENTATION

Project 21-3 FY '90 and FY '92

Instrumentation for Measuring Scour at Bridge Piers and Abutments

Research Agency: Resource Consultants, Inc.
Principal Invest.: Drs. Everett V. Richardson and Peter F. Lagasse
Effective Date: December 4, 1989; April 1, 1992

Completion Date:	June 3, 1992	March 30, 1994
Funds:	$305,922	$260,000

There are approximately 575,000 highway bridges in the nation's National Bridge Inventory. Of these, 85 percent are over streams or rivers. This level of exposure to the scouring action of floods dictates the need for expeditious development and implementation of reliable scour evaluation and related bridge inspection practices. The importance of this is supported by the 80 flood-related failures that have occurred in the past 3 years. Nationally, the annual cost for scour-related bridge failures has been determined to be $30 million.

In late 1988, the FHWA issued a Technical Advisory titled "Scour at Bridges." The advisory is intended to provide guidance to the states for developing and implementing a scour evaluation program. The program is intended to be applicable to the design of new bridges, evaluation of existing bridges, and implementation of scour countermeasures.

In many cases, current scour evaluation procedures predict scour depths greater than indicated by experience. If a bridge is determined to be scour critical, a countermeasure is recommended by the Technical Advisory, but the cost of these countermeasures is often prohibitive. One alternative to conventional countermeasures is to monitor actual scour activity to determine if significant scour affecting bridge safety has occurred. A secondary benefit may be to provide site-specific data to determine if currently used scour equations are applicable to that site. However, no scour monitoring device has yet been demonstrated to be effective under the range of environmental conditions encountered at a bridge during a flood.

Research is needed to develop low-cost, reliable, scour monitoring devices that can be mounted to a bridge to indicate the maximum scour depth that occurs at bridge piers and abutments during floods.

The objective of this research is to develop, test, and evaluate instrumentation that would be both technically and economically feasible for use in monitoring maximum scour depth at bridge piers and abutments.

Mandatory criteria for these devices is as follows:

- Capability for installation on or near a bridge pier or abutment.
- Ability to measure maximum scour depth within an accuracy of ± 1 foot.
- Ability to obtain scour depth readings from above the water or from a remote site.
- Operable during storm and flood conditions.

In addition, a set of desirable criteria has also been specified for these devices:

- Capability to be installed on most existing bridges or during construction of new bridges.
- Capability to operate in a range of flow conditions.
- Capability to withstand ice and debris.
- Relatively low cost.
- Vandal resistant.
- Operable and maintainable by highway maintenance personnel.

Phase I of the project performed a screening of possible technologies in order to identify the most promising methods for scour monitoring. A series of hydraulic flume studies was performed to further eliminate technologies that did not meet the proposed mandatory or desirable criteria and to improve or refine those that performed reasonably well.

On the basis of the Phase I results, a second phase of work was initiated in mid-1992 with the objective of further developing the most promising technologies and installing a range of systems and devices in the field for further evaluation. The specific objectives of Phase II are to determine: (1) long-term performance of the recommended systems, (2) costs and methods associated with their installation, and (3) costs and problems associated with their long-term maintenance.

Through December 31, 1993, work on Phase II has progressed on schedule. Several field installations have been implemented, and a draft final report documenting several simple systems is anticipated in early 1994.

Project 21-4 FY '91

Sealing Geotechnical Exploratory Holes to Protect the Subsurface Environment

Research Agency:	Strata Engineering Corporation
Principal Invest.:	C. Mirza
Effective Date:	March 1, 1991
Completion Date:	December 31, 1993
Funds:	$339,510

Geotechnical exploratory holes often penetrate water-bearing formations. There is concern that these holes can become conduits for contamination, co-mingling, or loss of groundwater. To protect the sub-surface environment, geotechnical organizations are being asked by water-resource agencies to use water-well drilling techniques and regulations that are not necessarily applicable to routine geotechnical practices. Moreover, use of water-well drilling methods and machinery for geotechnical exploration results in considerably higher costs to geotechnical organizations (including highway agencies) to modify procedures and obtain new equipment. Research is needed to develop suitable seals, which will adequately protect the subsurface environment, for closure and for installation of instruments in smaller diameter geotechnical exploration holes.

The objectives of this research are to develop (a) technical guidelines for materials and methods for placing seals in instrumented holes and for decommissioning small-diameter geotechnical exploratory holes in order to protect ground-

water from contamination and loss, and (b) methods for verification of the effectiveness of these seals.

The research will include at least the following tasks: (1) Summarize the state of the practice in sealing small diameter geotechnical exploratory holes. The summary shall include a list of viable seals using readily obtainable materials for both instrumented and noninstrumented holes. (2) Using the list developed in Task 1, develop and perform a testing program for the viable seals. The type and extent of testing of the sealing systems should be sufficient to evaluate: (a) the effectiveness and limitations of each sealing material; (b) the long-term performance of each seal; (c) the performance of each seal when subjected to naturally occurring salts, minerals, acids, and the like; (d) the influence of seal thickness (vertical dimension); (e) the ability to satisfactorily seal small annular spaces in instrumented holes; (f) the constructibility of each seal type, above and below groundwater, in artesian conditions, and at various depths below the ground surface to a maximum depth of about 200 feet; and (g) the influence of various geological conditions on the performance of each seal type. (3) Develop procedures to verify that the seal in situ will perform as intended. (4) Develop comprehensive guidelines for sealing geotechnical exploratory holes. This would include seal design procedures, schematics showing each seal design, specifications for each seal material, suitable placement techniques, and verification procedures, (5) Prepare a final report describing the research performed and presenting the comprehensive guidelines. Sufficient research results must be included in the report to conclusively justify the recommended guidelines.

Research is proceeding satisfactorily both at Strata Engineering Corporation and through a major subcontract with the University of Massachusetts at Amherst. The project received publicity when several members of the research team made presentations at the TRB Special Summer Meeting on Geotechnical Exploratory Holes in Albany, N.Y.; a meeting in conjunction with 42nd Annual Highway Geology Symposium. The project is nearing completion. The principal investigators are preparing the preliminary draft final report, which will then be reviewed by the project committee.

Project 21-5 FY '92

Determination of Unknown Subsurface Bridge Foundations

Research Agency:	Olson Engineering, Inc.
Principal Invest.:	Mr. Larry D. Olson
Effective Date:	April 27, 1992
Completion Date:	January 26, 1995
Funds:	$350,000

There are approximately 580,000 highway bridges in the National Bridge Inventory. For a large number of older non-federal-aid bridges, and to a lesser extent federal-aid bridges, there are no design or as-built bridge plans, and there is little or no information available to document the type, depth, geometry, or materials incorporated into the foundations. Preliminary estimates of the number of such bridges range from 10 percent to 25 percent of the total national highway bridge population.

The Federal Highway Administration now requires state transportation departments to perform screenings and evaluations of all bridges over rivers or streams to determine their susceptibility to scour; however, information on bridge foundations is necessary to perform such evaluations. Similar information on foundations is also needed for seismic evaluation of bridges.

Research is needed to develop practical methods and functional equipment to determine subsurface bridge foundation characteristics such as type, depth, geometry, and materials when little or no information is available. There is a need to determine the practicality, feasibility, and initial and operational costs for concepts, methods, and equipment that will provide a means for determining subsurface foundation characteristics. Off-the-shelf methods and equipment may be available that can be adapted for this purpose. New or previously proposed concepts may require basic modeling, research, and development in order to determine feasibility for application to this problem.

The objective of this project is to evaluate, develop, and test concepts, methods, and equipment that will enable the determination of subsurface bridge foundation characteristics where this information is not available, is unknown, or is uncertain. It is anticipated that the research will include the following tasks:

Task 1. Review and summarize existing, proposed, and conceptualized domestic and foreign technologies having promise for use in determining unknown subsurface bridge foundation characteristics such as type, depth, geometry, and materials. The review should be interdisciplinary, comprehensive, and consider technology transferable from other sources in addition to the highway industry.

Task 2. Develop an analytical process for screening and evaluating concepts, methods, and equipment which can be applied to the determination of unknown subsurface bridge foundation characteristics. As a minimum, the process must consider the ability of the concept, method, or equipment to identify the foundation type, foundation material, and geometry (including depth, size, and number of elements) under differing geologic, hydraulic, and hydrologic conditions.

Task 3. Evaluate the concepts, methods, and equipment that were identified in Task 1 using the screening and evaluation process developed in Task 2 noting advantages, limitations, developmental costs, initial and operating costs, and other important features and considerations. Provide recommendations on the concepts, methods, and equipment that show promise for further development and testing.

Task 4. Document the findings of Tasks 1 through 3 in an interim report to be submitted not later than 10 months

after initiation of the study. The interim report shall include a detailed research plan for evaluating and testing as many of the recommended concepts, methods, and equipment as are feasible under the remaining project budget. The detailed research plan may require the performance of mathematical or physical model studies, laboratory studies, and/or field evaluations. NCHRP approval of the interim report and the detailed research plan shall be required before proceeding with the remaining tasks.

Task 5. Perform the studies and evaluations in accordance with the NCHRP approved research plan.

Task 6. Summarize the results of the studies and evaluations conducted under Task 5. Recommend concepts, methods, and equipment that provide a means for determining subsurface foundation characteristics, specifically noting the advantages and limitations of each. Provide an estimate of the initial and operational costs for those methods and equipment that can be readily implemented in the field. Provide a plan which includes estimates of the cost and time necessary to fully develop and validate the recommended concepts, methods, or equipment which can not be readily implemented in the field at this time.

Task 7. Submit a final report documenting all research findings.

An interim report, documenting the findings of Tasks 1 through 4 and proposing technologies worth additional research, was submitted, reviewed, and revised in 1993. Formal field investigations and research based on the interim report are underway. A draft final report documenting the research is expected in late 1994.

AREA 22: VEHICLE BARRIER SYSTEMS

Project 22-5 FY '84

Develop Performance Standards and Hardware for Low Service Level Guardrail Systems

Research Agency: Southwest Research Institute
Principal Invest.: L. R. Calcote and K. Hancock
Effective Date: May 1, 1985
Completion Date: January 31, 1989
Funds: $200,000

Currently operational guardrail systems have been developed for 60-mph, 25-degree impacts with 4,500-lb vehicles. The use of design criteria based on this severe test condition has resulted in relatively expensive installations (e.g., high-cost terminal anchorage systems). For low service level roads, there is a need to determine the conditions under which less stringent guardrail requirements are warranted in order to reduce costs while providing safety performance based on demonstrated need.

The objectives of this project were: (1) to examine the need for guardrails on low service level roads and develop performance standards for guardrails, transitions, and terminals and (2) to design, test, and develop low-cost guardrail systems based on these performance standards.

Four low-service-level barrier systems were developed and crash tested during this project. The correlation of the crash test conditions with field conditions will take place as part of NCHRP Project 22-5A.

Project 22-5A FY '87

Warrants for the Installation of Low Service Level Guardrail Systems

Research Agency: Wilbur Smith Associates
Principal Invest.: Louis B. Stephens, Jr.
Effective Date: May 1, 1990
Completion Date: January 31, 1992
Funds: $100,000

Most operational guardrail systems in the United States have been developed to contain a 4,500-lb vehicle impacting at 60 mph and 25 deg. The use of design criteria based on these test conditions has resulted in relatively expensive guardrail installations. For low-service-level roads, there is a need to determine the conditions under which less stringent guardrail requirements are warranted in order to avoid excessive expenditures and provide safety performance based on demonstrated need.

Four low-service-level barrier systems were developed under NCHRP Project 22-5 to address this need. Through full-scale crash testing, these systems were shown to contain a 3,400-lb vehicle impacting at 50 mph and 20 deg. It is anticipated that these barriers can be used to improve the level of safety on low-service-level roads; however, correlation of the crash test conditions with field conditions is required. In addition, a user's guide is needed to provide design details for the systems developed and specific warrants for their placement on low-service-level roads.

The objectives of NCHRP Project 22-5A are to develop warranting procedures for the placement of the barrier systems developed under NCHRP Project 22-5, and to prepare a user's guide which contains design drawings for these systems and warranting procedures for their placement.

This research shall include at least the following tasks:

Task 1—Determine the range of roadway characteristics for which it would be appropriate to install the barrier systems designed and crash tested under Project 22-5. In addition, estimate the installed cost for each of these barrier systems. A letter report containing the findings of this task shall be submitted to NCHRP. Panel approval of the letter report is required before proceeding to Task 2.

Task 2—Using the findings of Task 1, develop specific warranting criteria for the placement of the barrier systems developed under Project 22-5. The product to be delivered by this effort will be warranting procedures in table and/or

chart form to guide the placement of these low-service-level barrier systems.

Task 3—Prepare a user's guide which contains the warranting procedures developed under Task 2 and design drawings for the barrier systems developed under Project 22-5. The guidelines shall also include estimated life-cycle cost data for each barrier system.

Task 4—Prepare a final report documenting the research conducted under NCHRP Projects 22-5 and 22-5A.

All research has been completed, and the final report has been submitted and reviewed by the project panel. A condensed version of the report will be published as an NCHRP Research Results Digest, and loan copies of the final report will be available from NCHRP.

Project 22-6 FY '85

Roadside Safety Design for Small Vehicles

Research Agency:	Texas A & M Research Foundation
Principal Invest.:	Dr. Hayes E. Ross, Jr.
Effective Date:	June 1, 1985
Completion Date:	May 31, 1988
Funds:	$350,000

Most current roadside safety appurtenances were designed and tested with passenger vehicles ranging from 4,500 down to 2,250 lb. Research is currently in progress to investigate the performance of hardware and roadside features with vehicles in the 1,800-lb range. Under some conditions, barrier impacts become increasingly hazardous for smaller vehicles; however, little is known about the performance of current hardware and roadside safety features with vehicles smaller than 1,800 lb.

The objectives of this project were (1) to assess the performance of selected existing highway safety appurtenances and roadside features with passenger vehicles below 1,800 lb and (2) to project the limits of vehicle characteristics that can be safely accommodated through improvements in current hardware and roadside features.

Research has been completed and the project report has been published as NCHRP Report 318, "Roadside Safety Design for Small Vehicles."

Project 22-7 FY '89

Update of "Recommended Procedures for Safety Performance Evaluation of Highway Appurtenances"

Research Agency:	Texas A&M University Research Foundation
Principal Invest.:	Dr. Hayes E. Ross, Jr.
Effective Date:	June 1, 1989
Completion Date:	August 31, 1992
Funds:	$200,000

The objective of this study is to update the recommended procedures for the safety performance evaluation of both temporary and permanent highway appurtenances in such a manner as to reflect advances in technology and to accommodate current and anticipated roadway and vehicle characteristics.

This project will consist of two phases to be performed consecutively, with a review required at the completion of Phase I on which authorization to proceed with Phase II will be based. The planned tasks are described, as follows:

Phase I

Task 1. Develop a comprehensive list of topics to be examined in updating the recommended procedures. This list shall be based on a critical review of past and on-going research, and input from knowledgeable individuals involved with and interested in the subject area.

Task 2. Evaluate the relative importance of each of the topics cited in Task 1 and identify important issues within each topic.

Task 3. Prepare an interim report documenting the efforts completed in Tasks 1 and 2. The interim report shall also include an annotated outline of the final report and a detailed work plan describing the activities required in Phase II. Submit the interim report to the NCHRP Project Panel for review and approval. A meeting between the research team and the NCHRP Project Panel will be planned at the completion of Task 3 to discuss the results of Phase I and the work planned for Phase II. The investigators shall prepare a revised interim report to reflect the outcome of the meeting and distribute it to the project panel members.

Phase II

Task 4. Using the information generated in Phase I, prepare a first draft of the final report and document, under separate cover, how each of the issues identified was resolved. The investigators will also prepare a proposed list of reviewers from the highway community-at-large for approval by the panel. A second meeting between the research team and the project panel will be planned at the completion of Task 4 to discuss the first draft of the final report, the list of issues identified and how they were resolved, and the proposed list of reviewers. The investigators will prepare a second draft of the final report to reflect the outcome of the second meeting and distribute the revised document to the project panel members and to the reviewers approved by the project panel in this task.

Task 5. Evaluate the reviewers' comments and prepare a brief discussion of the comments and their disposition. Based on the results of this effort, prepare a third draft of the final report. A third meeting between the researchers and the NCHRP Project Panel will be scheduled at the completion of Task 5 to discuss the comments received from the community-at-large, the disposition of those comments, and the third draft of the final report.

Task 6. A final report will be prepared based on the

outcome of the third meeting between the researchers and the NCHRP Project Panel.

The final report has been approved, and it has been published as *NCHRP Report 350,* "Recommended Procedures for the Safety Performance Evaluation of Highway Features."

Project 22-8 FY '89

Evaluation of Performance Level Selection Criteria for Bridge Railings

Research Agency:	Texas A&M University Research Foundation
Principal Invest.:	King K. Mak
Effective Date:	April 15, 1989
Completion Date:	December 31, 1993 (pending)
Funds:	$200,000

The objectives of this research are (1) to determine the adequacy and validity of the performance levels and the performance-level selection procedures contained in the "Guide Specifications," (2) to estimate the impact of implementing the "Guide Specifications" on state and local agencies, (3) to recommend appropriate improvements to the "Guide Specifications," and (4) to evaluate the feasibility of extending the multiple performance-level approach to all longitudinal barrier systems.

This research will be undertaken with the following tasks:

Task 1. Review the literature for information on the multiple performance-level concept, barrier warrants, barrier design, vehicle crash testing, car and truck accident studies involving vehicle contact with bridge railings and other longitudinal barrier systems, and any other related subjects deemed appropriate by the researchers. In addition, identify accident data bases that can be used to validate the criteria used to develop the performance levels identified in the "Guide Specifications."

Task 2. Evaluate the information assembled in Task 1 and develop a working plan for evaluating and validating the performance levels and performance-level selection procedures contained in the "Guide Specifications." Prepare and distribute to the NCHRP Project Panel a letter report describing the results of Tasks 1 and 2.

Task 3. Evaluate the sensitivity of the performance level criteria in accordance with the work plan prepared in Task 2. Document any problems with the software used to develop the guide specifications and make necessary modifications. Reproduce the barrier performance level tables as necessary and reassess the sensitivity after any modifications to the software.

Task 4. Develop a detailed working plan for applying the performance-level selection procedures to a representative sample of state, county, and city roadways for: (a) estimating the impact of implementing the "Guide Specifications"; (b) assessing the effects of implementing the potential modifications to the "Guide Specifications"; and (c) evaluating the sensitivity of the performance-level selection procedures to variations in actual roadway and traffic characteristics.

Task 5. Compare the revised barrier performance selection tables generated in Task 3 with the existing "Guide Spec." Discuss the implications of differences in these tables on the design requirements to which the states must comply. Data from typical bridges obtained from states will be used to indicate the implications. The findings of Tasks 1 through 5 will be documented in an interim report. A meeting with the project panel will be convened to discuss the interim report and assess its implications.

Task 6. Evaluate the feasibility of extending the multiple performance-level concept to all longitudinal barriers. Prepare a series of white papers describing improvements to the analysis software and procedures, as well as basic research needs, deemed necessary to evaluate roadside safety. Develop a plan for a roadside-appurtenance design guide that can be used for a wider application of the multiple performance level concept. The plan should include an identification of variables involved, the appropriate methodologies for accommodating these variables, and a strategy for validating the approach.

Task 7. Prepare a final report documenting the efforts and findings of the project.

The revised final report is under review by the project panel. The decision on publishing the report is pending.

Project 22-9 FY '91

Improved Procedures for Cost-Effectiveness Analysis of Roadside Safety Features

Research Agency:	Texas A & M University
Principal Invest.:	King K. Mak and Dean L. Sicking
Effective Date:	September 1, 1991
Completion Date:	August 30, 1995 (pending)
Funds:	$250,000

The 1988 AASHTO "Roadside Design Guide" includes general warrants for the use of traffic barriers and other safety appurtenances. However, these warrants do not address the cost-effectiveness of such installations. The "Roadside Design Guide" also includes information on a computer program, ROADSIDE, which was developed for cost-effectiveness analyses, but agencies attempting to use ROADSIDE have experienced difficulties, and some have found the results questionable.

An NCHRP study is underway to update *NCHRP Report 230,* "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances." It is expected that this update will include procedures for establishing various performance levels for roadside features. The intent of the performance-level test criteria is to provide safety features that are better tailored to the specific conditions of a site. The current version of ROADSIDE does not readily allow

the analysis of different performance levels. Research is needed to develop improved software for cost-effectiveness analysis of roadside features and to formulate procedures for using the software to apply the performance levels concept.

The objective of this project is to develop improved microcomputer-based cost-effectiveness analysis procedures for use in (1) assessing alternative roadside safety treatments at both point locations and sections of roadway and (2) developing warrants and guidelines including those which consider performance levels of safety features. To achieve these objectives the project will include at least the following tasks:

Phase I

Task 1. Identify and assess current procedures, both manual and computerized, for cost-effectiveness analyses related to the selection of roadside safety features. ROADSIDE and the FHWA program BCAP shall be included in the assessment.

Task 2. Conduct a detailed evaluation of the most promising procedures and software. This evaluation shall be performed to assess the strengths and limitations including, at a minimum, range of applicability, ease of use, data requirements, and flexibility. Evaluations shall also include a limited survey of user experience with the procedures and software.

Task 3. Prepare an Interim Report documenting the efforts completed in Tasks 1 and 2, and recommending a course of action (e.g., upgrade existing software, develop a new procedure) to meet the project objective. The interim report shall include a description of the software and procedures proposed and a detailed work plan describing the activities that will be performed in Phase II. The interim report will be submitted to the NCHRP project panel within 6 months of the contract start date. A meeting of the NCHRP project panel and researchers will be held at the completion of Task 3 to discuss the results of Phase I and the recommended course of action, and to agree on a plan of work for Phase II.

Phase II

Task 4. Upon notification to proceed with Phase II, develop improved software and procedures for its use. The software shall be able to operate on an IBM-compatible microcomputer at a reasonable speed, using a commonly available language that does not require additional end-user hardware or software acquisition.

Task 5. Test, modify, as necessary, and validate, the improved software and procedures using existing data bases applied to actual highway locations.

Task 6. Develop procedures for user agencies to establish system-wide warrants for common situations through use of the software.

Task 7. Prepare a user's manual, which describes the capabilities and limitations of the system, and provides instructions for operating, customizing, and updating the system. The user's manual shall also include a variety of examples depicting program inputs and outputs. These examples shall, as a minimum, include a spot location, a highway section, a performance-level-based analysis, and the development of generalized system-wide warrants.

Task 8. Prepare and submit a Final Report documenting the research effort. The final report should contain descriptions of the procedures developed, and documentation of the functions and application of the computer software. It should also include application examples, the user's manual, and the software documentation. The contractor will be required to submit an executable version of the software and its source code.

The analysis approach was reviewed in detail at the interim meeting and tentatively approved.

Project 22-10 FY '91

Updated Materials for a Traffic Barrier Hardware Guide

Research Agency: Momentum Engineering, Inc.
Principal Invest.: Malcolm Ray
Effective Date: January 2, 1991
Completion Date: December 31, 1994
Funds: $300,000

A June 1979 publication, entitled "A Guide to Standardized Highway Barrier Rail Hardware," was prepared by the AASHTO-AGC-ARTBA Joint Cooperative Committee. It has been used widely by highway agencies to develop standard barrier designs and plans. The 1979 Guide is in need of revision because of the many changes that have occurred in traffic barriers since its publication. For instance, the recently published "AASHTO Roadside Design Guide" includes new crashworthy barrier systems that have resulted from recent research. A new and expanded guide will be beneficial to highway agencies, designers, and suppliers of barrier hardware. The AASHTO-AGC-ARTBA Joint Cooperative Committee's Task Force 13 has requested, and AASHTO has authorized, the NCHRP to develop recommendations for a new and expanded guide.

The objective of this project is to prepare, in printed and CAD formats, materials for a recommended replacement of the 1979 publication entitled "A Guide to Standardized Highway Barrier Rail Hardware." Accomplishment of this objective will require, as a minimum, the following tasks:

Task 1. Obtain and review relevant research and testing information, particularly on work that has been done since 1979. Identify all of the hardware items related to roadside barriers, median barriers, temporary barriers, bridge railings, transitions, terminals, and crash cushions that might be included in an up-to-date hardware guide.

Task 2. Request all states furnish their standard traffic barrier details. Identify those items that should be considered

for inclusion in an up-to-date hardware guide. Request related hardware details from suppliers and manufacturers. All crashworthy systems now in use should be considered, as well as new hardware that is expected to come into use in the near future. Only hardware that is in the public domain shall be included in the revised hardware guide.

Task 3. Prepare an interim report summarizing the relevant research, proposing selection criteria, and recommending barrier hardware to be included in the guide. The interim report shall describe the proposed organization and format of the materials to be included in the new guide. Sample Intergraph-compatible CAD drawings and layouts for printed materials shall be provided. The contractor shall recommend methods for organizing the CAD files, maintaining the guide, and disseminating future updates. Sample CAD files shall be submitted to the NCHRP project panel to verify that they can be used on an Intergraph System.

Task 4. Following panel review of the interim report, meet with the NCHRP panel to discuss the report and resolve any open issues. At the meeting, the contractor shall describe proposed revisions to the interim report for panel approval. The format, organization, and hardware details to be included in the recommended replacement for "A Guide to Standardized Highway Rail Barrier Hardware" shall be established at this meeting.

Task 5. Prepare draft materials for the guide including detailed drawings for each hardware item, material specifications, references relating to crashworthiness, and descriptions of intended use. When developing the guide, the contractor shall verify the accuracy of the drawings, text, and references and the current applicability of the referenced specifications. Some 35 copies of draft materials shall be submitted for review by the NCHRP panel and the Barrier Committee of Task Force 13. The contractor shall evaluate the reviewers' comments and prepare a written response discussing each comment and indicating the recommended disposition.

Task 6. Prepare the recommended guide in a format which will facilitate modification in the future. The recommended guide shall be prepared as a stand-alone document for submittal to Task Force 13. The drawings in the final guide shall be put on an Intergraph-compatible CAD system to be made readily available. Two copies of all computer media for the text, graphics, and drawings shall be submitted to the NCHRP.

Task 7. Prepare a final report which describes the efforts of this project and summarizes the research findings. It shall include the recommended replacement guide and any CAD documentation as an appendix.

Draft hardware details from the first phase efforts are under review by the panel and the AASHTO-AGC-ARTBA Task Force 13. A continuation phase has been initiated to develop additional materials and permit further review and revision.

Project 22-11 FY '94

Evaluation of Roadside Features to Accommodate Vans, Mini-Vans, Pickup Trucks, & 4-Wheel Drive Vehicles

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	24 months
Completion Date:	
Funds:	$200,000

The ISTEA (Intermodal Surface Transportation Efficiency Act of 1991) requires that the Secretary of Transportation

> . . . shall issue a final rule regarding the implementation of revised guidelines and standards for acceptable roadside barriers and other safety appurtenances, including longitudinal barriers, end terminals, and crash cushions. Such revised standards shall accommodate vans, mini-vans, pickup trucks, and 4-wheel drive vehicles and shall be applicable to the refurbishment and replacement of existing roadside barriers and safety appurtenances as well as to the installation of new roadside barriers and safety appurtenances. (Section 1073, Public Law 102-240, 12/18/91)

This ISTEA requirement creates the need to (1) determine if vans, mini-vans, pickup trucks, and 4-wheel drive vehicles (hereafter referred to as light trucks) have impact behaviors different from the previously tested passenger vehicles, and (2) assess the adequacy of current design guidelines and standards for roadside barriers and safety appurtenances. (For this project, roadside barriers and safety appurtenances will be referred to as roadside features. Roadside features shall include, but not be limited to, permanent and temporary traffic barriers, crash cushions, terminals, truck-mounted attenuators, breakaway supports, cross-sectional elements, and terrain.)

There has only been limited research on the safety performance of light trucks for several reasons. One reason is that until recently, crash testing for roadside features only required the use of passenger cars. Another reason is the relatively recent emergence of many types of light trucks for use primarily as passenger vehicles. A final reason is that only in the last few years have accident data become available to permit the study of vehicles in this class. The research that has been undertaken suggests, however, that (1) a higher fatality rate exists for some run-off-the-road accidents involving light trucks, (2) higher centers of gravity may result in a greater propensity to roll over during or after interaction with a roadside feature, and (3) this class of vehicles represents more than 25% of the fleet and may grow to represent a third of the vehicle fleet.

Research is needed to evaluate the safety performance of current roadside features for light trucks. Specifically, the need exists to determine which combinations of roadside

features and subclasses of light trucks represent the greatest potential for safety problems. Further, the need exists to assess the adequacy of current standards and guidelines for the design, placement, and testing of roadside features related to light trucks.

The objectives of this research are to 1) evaluate current information on the safety performance of road-side features for each subclass of light trucks, 2) assess the significance of gaps in safety performance information, and 3) recommend priorities for future research, testing, and development needed to ensure that roadside features accommodate light trucks.

To accomplish the project objectives, the following tasks are envisioned:

Task 1. Review information on the performance of roadside features with each subclass of light truck vehicle. Include data from sources such as crash tests, accident studies, in-service evaluations, simulation, insurance claim experience, and so on. Contact transportation agencies, knowledgeable professionals, and highway safety advocates to identify relevant experience and anecdotal evidence. Submit a summary and critique of the findings of this task to the panel.

Task 2. Identify all types of vehicles in the light truck class that may constitute a significant portion of the vehicle fleet in the United States within the next 10 years and define subclasses appropriate for this research. For each subclass, define the range of static and dynamic properties (e.g., center of gravity, mass) and vehicle dimensions (e.g., bumper heights, wheelbase) required for the evaluation of its safety performance relative to roadside features.

Task 3. Identify specific roadside features for study in this project. Emphasis should be given to features commonly found or presently being installed in significant quantities.

Task 4. Identify appropriate factors for the evaluation of safety performance considering accident frequency and severity, the criteria in NCHRP Report 350, and other factors. Develop a scheme for comparison of the selected safety performance factors over the range of roadside features and subclasses of light trucks. Use existing information on the safety performance of passenger cars relative to the roadside features as a benchmark in the comparisons. Submit a working paper that describes the scheme and how it will be used to assess the safety performance for the defined ranges of roadside features and subclasses of light trucks.

Task 5. Conduct preliminary comparisons of safety performance for the various subclasses of light trucks using readily accessible data and analysis methods to generate inferences as to where the most critical problems may exist. These comparisons can be based on the analysis of crash data, accident records, simulation results, or other information.

Task 6. Prepare an interim report that describes the vehicles and roadside features identified, presents the results of the preliminary comparisons, and outlines a detailed work plan(s) for further evaluations of the safety performance of roadside features for each of the subclasses of light truck vehicles. Meet with the project panel to discuss the results and to select the roadside features and vehicle types that will be the focus of the subsequent tasks.

Task 7. Conduct the data collection, manipulation, and analysis efforts outlined in the approved work plan as necessary to verify the preliminary analyses and to fill gaps in existing information about safety performance of roadside features with the various subclasses of light trucks. Document the sources of information and the procedures used in this effort for possible future use.

Task 8. Synthesize the findings to provide a basis for recommendations for future research, crash testing, and development of roadside features to accommodate vans, minivans, pickup trucks, and 4-wheel drive vehicles. Recommend priorities for research and development efforts to address the most critical safety issues, and assess the adequacy of design standards and crash-testing procedures for this vehicle class.

Task 9. Prepare a Final Report that describes the entire research effort and includes all documentation necessary to support the research needs defined.

AREA 23: SOILS PROPERTIES

No projects

AREA 24: SOIL MECHANICS AND FOUNDATIONS

Project 24-3 FY '86

Laboratory Evaluation of Piles Installed with Vibratory Drivers

Research Agency: University of Houston

Principal Invest.: Drs. Michael W. O'Neill and Cumaraswamy Vipulanandan
Effective Date: January 6, 1986
Completion Date: August 31, 1988
Funds: $200,000

State Departments of Transportation often are requested by contractors to use vibratory drivers rather than the more conventional impact hammers to install piles. Vibratory pile drivers can provide substantial savings by reducing the amount of driving time to final penetration under certain soil conditions. However, the lack of a reliable dynamic method of estimating bearing capacity limits their usefulness. Presently, the most common method to determine capacity is to restrike the pile with an impact hammer, but the validity of this method is unproven and the extra operation reduces the potential savings.

Developing a reliable method for dynamically determining bearing capacity of piles installed with vibratory drivers

is a complex problem. Laboratory studies were needed to provide insight into the basic behavior of piles installed with vibratory drivers compared to impact hammers and the influence of various soil parameters on the behavior of piles. Laboratory studies would also assist in the design of future field tests and the analysis of results.

The overall objective of this study was to evaluate the load-deformation behavior of piles installed in the laboratory with vibratory drivers. Specific objectives included: (1) a comparison of load deformation behavior of piles installed with vibratory drivers and impact hammers; (2) the identification of soil parameters that significantly affect load-deformation behavior of piles installed with vibratory drivers; (3) a comparison of load-deformation behavior of piles installed by vibratory drivers with and without restriking using an impact hammer to evaluate the effect of restriking; and (4) the development of a recommended predictive method of determining bearing capacity for further field verification.

Research is complete, and the principal findings have been published in NCHRP Report 316, "Laboratory Evaluation of Piles Installed with Vibratory Drivers." Additional detail on the various experiments is available in an agency report titled, "Supplement to NCHRP 316, Laboratory Evaluation of Piles Installed with Vibratory Drivers, Appendices B-Q." The supplemental report was distributed to NCHRP sponsors only. However, others may obtain loan copies or purchase ones for the cost of reproduction (see final page of this document for ordering information).

Project 24-4 FY '87

Load Factor Design Criteria for Highway Structure Foundations

Research Agency:	Virginia Polytechnic Institute and State University
Principal Invest.:	Richard M. Barker, James M. Duncan, Kamal B. Rojiani
Effective Date:	September 1, 1987
Completion Date:	February 28, 1991
Funds:	$459,152

The objectives of this research were to develop (1) recommended specification provisions for highway structures foundation design, based on the load factor design philosophy, and (2) engineering manuals to assist in the design of foundation and substructure elements. The existing (14th edition) AASHTO *Standard Specifications for Highway Bridges* includes provisions for superstructure design based on allowable stress design methods or load factor design methods. However, only allowable stress design specification provisions are included in the *Standard Specifications* for the design of substructures, abutments, and retaining walls.

Research has been completed and the final report published as NCHRP Report 343, "Manuals for the Design of Bridge Foundations." The report contains 5 engineering manuals which provide a discussion on the methods and procedures recommended for the design of the various foundation and substructure elements, along with relevant code and commentary information and worked example problems. The 5 manuals cover driven piles, drilled piers, spread footings, abutments and retaining walls, and criteria for tolerable settlements. In addition, Report 343 includes complete recommended specification and commentary provisions for incorporation into Articles 4, 5 and 7 of the AASHTO *Standard Specifications for Highway Bridges.* AASHTO adopted the recommended specification provisions in 1992; they will be published by AASHTO as part of the 1993 Interim Specifications in mid-1993.

Project 24-5 FY '88

Downdrag on Bitumen-Coated Piles

Research Agency:	Texas A&M Research Foundation
Principal Invest.:	Dr. Jean-Louis Briaud
Effective Date:	June 15, 1988
Completion Date:	December 14, 1993
Funds:	$385,000

Foundation piles are subject to downdrag forces whenever the soil surrounding them settles. The settlement of thick compressible soils under embankments can cause downdrag forces significantly larger than the structural load the pile must carry. This additional load may result in unacceptable settlements of the piles or even failure of part of the pile group.

Downdrag forces have been reduced by coating the piles with bitumen. Several approaches for predicting and reducing downdrag forces have been published but little verification of design methods and material properties is available.

Research is needed to verify and improve the present state of the art in both design and construction techniques for using bitumen-coated piles. This research is expected to improve design and testing procedures for practical use and to provide a basis for design confidence.

The overall objective of this research is to develop practical guidelines for use of bitumen-coated piles including: (1) coating material specifications and tests, (2) design techniques, and (3) construction practices.

The contract has been amended to allow more comprehensive field testing and analysis, as well as enhancements of the NEWNEG computer programs, and to produce a video tape to accompany the recommendations in the final report. Funding for an additional continuation phase has been approved to allow assessment of the environmental aspects of possible contamination when the bitumen is in contact with groundwater.

The preliminary draft final report has been submitted and is being reviewed by the project committee.

Project 24-6 FY '93

Expert System for Stream Stability and Scour Evaluation

Research Agency: University of Washington
Principal Invest.: Dr. Richard Palmer & George Turkiyyah
Effective Date: March 15, 1993
Completion Date: March 14, 1995
Funds: $250,000

Many structures maintained by transportation agencies are constructed over waterways that are susceptible to various degrees of scour and stream instability. If not prevented or arrested, scour and instability can ultimately lead to catastrophic failure, with possible loss of human life and high cost of facility replacement. Relatively few experts exist who can use their judgment and experience to effectively address scour and stream stability problems, and, yet, the solution to these problems invariably relies on such individuals. The nature and importance of the problem lead to the potential application of knowledge-based expert systems technology. These systems are particularly applicable to "ill-structured" problems, where a mathematical solution is not available or is impractical, and the problem must be solved using expert skill, judgment, and experience.

One area of particular concern is the need to provide assistance to field investigators in the assessment of existing structure sites for the potential dangers of scour and stream instability. Field investigators must be aware of the types of data required to make decisions and identify sites for more detailed evaluations.

The objective of this research is to develop an operational, microcomputer-oriented, knowledge-based expert system to advise field personnel in evaluating current and potential scour and stream stability problems and in identifying the urgency for appropriate countermeasures or additional detailed analyses. The resulting information shall be suitable for use by others in the performance of detailed engineering analyses if required. The system shall operate on field-worthy equipment and use selected analytical and heuristic models, in addition to its primary function of capturing the expertise of one or more experts in hydraulics, structures, geology, and structure maintenance and inspection. Transportation agencies will use the system to improve the productivity and effectiveness of structure inspection, maintenance, and replacement programs.

Accomplishment of this objective will require at least the following tasks: (1) Identify parameters and site conditions necessary to evaluate current and potential inland stream stability and scour problems. Examples of parameters and site conditions include, but are not limited to, basin characteristics, soil types, flow regime, plan forms, and cross-section geometry. Other factors to be considered are bank stability, aggradation and degradation, and lateral migration. (2) Determine the relationships among parameters and site conditions and their relative importance for use in predicting trends in stream stability and scour potential. (3) Develop a conceptual plan for the expert system. This will include: system input, technical design, and system output as well as the basis by which the system will be tested and validated. The plan will be supported with the logic and concepts from which the expert system will be developed. This plan will be submitted to NCHRP for review and approval prior to the commencement of subsequent tasks. The system shall include at least the following features: • Minimize variations in responses among users through the use of standardized graphic images and photographs. • Serve as a diagnostic tool for bridge inspectors and maintenance personnel to assist in (1) selecting bridge rating codes for Items 60, 61, 71, and 113 on the Federal Highway Administration Structure Inventory and Appraisal Sheet; and (2) monitoring conditions that indicate the changing level of stability and scour at structure sites. • Be consistent with stream classifications found in the "BRI-STARS Expert System for Stream Classification." • Provide advice to the user on the relative levels of instability of the stream and the categories of countermeasures or other potential courses of action to be considered. • Provide judgments sufficient to advise maintenance personnel or bridge inspectors when expertise outside of their purview is needed. • Generate reports that present pertinent information and graphics. The reports shall be capable of being produced on a variety of commonly used output devices. • Provide a capability for modification of decision logic variables such that local conditions can be more accurately represented. (4) Implement the conceptual plan developed and approved in Task 3. (5) Test and evaluate the expert system. (6) Refine the expert system and incorporate changes. (7) Prepare a final report documenting the research effort and provide all expert-system software including a well-documented version of the source code on diskette. A user's manual and program documentation manual will be appended to the final report. Any and all software developed will remain the property of the NCHRP and cannot be licensed and sold solely by the developing individual.

Research on Tasks 1 through 3 has been completed and work is proceeding on the other tasks.

AREA 25: IMPACT ANALYSIS

This area became effective January 1, 1979, and includes only those projects beginning with the FY 1981 program. Refer to Areas 7, 8, and 20 for previous projects in the realm of Impact Analysis.

Project 25-2 FY '88

Predicting Stop-and-Go Traffic Noise Levels

Research Agency: Vanderbilt University
Principal Invest.: Dr. William Bowlby
Effective Date: January 18, 1988

Completion Date: May 31, 1989
Funds: $64,999

STAMINA 2.0 has become the standard computer-based noise prediction model to aid in the assessment of existing and future noise levels on highway projects. It has the versatility to use several ranges of factors (or data) to predict noise levels for many types of conditions. However, STAMINA deals with free flowing traffic traveling at least 30 miles per hour. It does not have the capability of dealing with stop-and-go conditions that are frequently encountered in urban areas and can be very different from normal free flow traffic conditions.

Noise analysts using STAMINA have been attempting to predict noise levels for stop-and-go conditions by using various approximations and engineering judgments, such as varying average vehicle speeds and emission levels. The analyst who assesses existing and future noise levels for environmental impact statements (EIS's) or environmental assessments (EA's) using STAMINA has no formally recognized basis for adjusting the program to adequately reflect stop-and-go conditions. Consequently, the error resulting from the use of these approximations can be significant.

Research was needed to develop a standard procedure for accurately assessing stop-and-go noise levels by adding additional emission level characteristics and other relevant factors to the STAMINA model. Therefore, the objective of this project was to develop a procedure for predicting stop-and-go traffic noise levels that could be input into the STAMINA 2.0 noise model.

Research is complete, and the principal findings and a prediction methodology have been published in NCHRP Report 311, "Predicting Stop-and-Go Traffic Noise Levels." Additional detail on the test sites and data and the evaluation techniques is available in an agency report titled, "Supplement to NCHRP 311, Predicting Stop-and-Go Traffic Noise Levels." The supplemental report was distributed to NCHRP sponsors only. However, others may obtain loan copies or purchase ones for the cost of reproduction (see final page of this section for ordering information).

Project 25-3 FY '89

Guidelines for the Development of Wetland Replacement Areas

Research Agency: URS Consultants
Principal Invest.: Thomas J. Denbow
Dr. Edgar W. Garbish
Effective Date: April 1, 1989
Completion Date: September 1, 1993
Funds: $299,711

Planning for highway projects frequently involves consideration of several mitigative alternatives to address adverse impacts to wetland resources. One alternative often used requires the development of wetland replacement areas as compensation for wetlands lost due to highway development projects. Although considerable information is available on the subject of wetland replacement, both in documented form and undocumented experience or practice, much of this information is fragmented and dispersed throughout the country, or has not been fully evaluated. Therefore, current information cannot be easily used for locating, designing, constructing, or monitoring wetland replacement areas. However, to ensure effective implementation of this important mitigative alternative, transportation planners, designers, environmental staff, and other users must have this information readily available. Therefore, there is a need to synthesize the present state of the art and from this synthesis develop a recommended process for replacing wetlands.

The objective of this research is to develop a manual containing a well-defined wetland replacement process, including guidelines and techniques for locating, designing, constructing, monitoring, and maintaining wetland replacement sites. The guidelines and techniques shall be organized on a geographic or ecological basis as appropriate. This objective will be accomplished by completing the following tasks:

Task 1. Examine existing wetland replacement data. Locate, assemble, and evaluate all available technical information and current research projects pertaining to the subject of wetland replacement.

Task 2. Interview personnel having wetland replacement experience. Meet with personnel from transportation and natural resource agencies, environmental and engineering consultants, and other organizations, who have been or currently are involved in wetland replacement efforts. These interviews shall determine the various wetland replacement processes; design and construction techniques; construction plans, specifications, and special provisions; and cost information now being used to develop wetland replacement areas. Problems, constraints, and special monitoring and maintenance requirements associated with these wetland replacement efforts are also to be identified.

Task 3. Collect field data. A detailed plan shall be developed to collect data to validate or supplement the information from Tasks 1 and 2. The plan must include a list of proposed types of data to be collected on existing wetland replacement projects considered successful and unsuccessful in terms of functions and values. A rationale for the data to be collected must also be provided. It is beyond the scope of this study to perform comprehensive field sampling. The detailed plan shall be submitted to NCHRP for review and approval. Upon approval, the plan shall be implemented.

Task 4. Develop wetland replacement process manual. Using the information collected under Tasks 1 through 3, develop a wetland replacement manual. The manual will provide a detailed process for determining the steps and factors that need to be considered in the location and general design of wetland replacement areas to fulfill regulatory and policy needs. On an ecological or a geographical basis, as appropriate, the manual shall also provide guidelines and techniques for site selection, analysis, and design; construc-

tion plans, specifications, special provisions, and cost estimates; monitoring; and maintenance.

Task 5. Preparation of final report. Prepare a final report that documents the research effort. As a minimum, the report shall include the following: (a) a description of the current state of the art on wetland replacement techniques, their effectiveness and practicality, using a combination of concise narrative, tables, and illustrations; (b) a discussion of the problems and constraints frequently encountered in the location, design, construction, monitoring, and maintenance of wetland replacement areas; (c) recommendations for policy changes and additional research; and (d) an assessment of the feasibility for developing a "knowledge-based expert system" based on the Task 4 manual. The Task 4 manual shall be part of the total final report package.

The Task 4 wetland replacement manual has been submitted and reviewed by the NCHRP panel. The manual is extensive, making panel review times long and subsequent modifications by the agency complex. During the life of this project, there has been significant interaction between the panel and researchers in general. These discussions have been quite fruitful, but have also caused several iterations on issues and parts of the manual. This project is significantly behind schedule.

Project 25-4 FY '92

Determining Economic Impacts on Adjacent Businesses Due to Restricting Left Turns

Research Agency: Cambridge Systematics, Inc.
Principal Invest.: Glen E. Weisbrod
Effective Date: June 15, 1992
Completion Date: July 15, 1994
Funds: $300,000

Generally, highway capacity and safety can be increased when left turns are restricted by signing or by positive median controls (e.g., median barriers or closure of median openings). However, such actions frequently are opposed by roadside-property owners and business operators. Their concern is for the loss of potential customers who can no longer make direct left turns. Loss of income or business failures have been cited as likely outcomes. The perception of adverse impacts on the economic viability of the immediate area, as well as the larger community, can sometimes impede or even stop planned roadway improvements. Little useful information is available on this subject. Research is needed to provide transportation agencies and business owners more information for the assessment of potential gains or losses.

The objective of this research is to determine the economic impacts, on adjacent businesses and property owners, due to restricting left-turn movements.

The scope of the research includes (1) quantification and analysis of the economic impacts on tenants and property owners through a series of field studies, and (2) development of procedures and tools for analyzing and predicting the effects of implementing left-turn restrictions on adjacent businesses to assist planning and evaluation of future projects.

Accomplishment of the objective will require the following tasks: (1) Conduct a literature search. Document the results and assemble an annotated listing of key items. (2) Develop a plan for conducting the field studies. It is anticipated that 20 sites can be included. The field studies shall be based on a sample of geographically diverse sites covering a range of population and development densities with varying ADT classifications. The field-studies plan should be based on the resources and techniques needed to conduct the effort, and the methods required to control or adjust for other factors that may affect the study (seasonal traffic fluctuation, regional economic changes, etc.). A detailed field-study plan shall be submitted for NCHRP panel review and approval no later than 6 months following project initiation. (3) Conduct the field studies in accordance with the plan developed in Task 2. (4) Analyze and summarize the data from the field studies and propose a methodology consisting of tools, models, and procedures including simple charts and nomographs. The models included in the methodology should be simple, however, where the data obtained in Task 3 allows, more sophiscated models may be proposed where it can be shown that such models can be validated for general use. These tools and procedures are intended to assist transportation agencies in determining the economic impacts on affected businesses in the planning and design phases of the project development process. Document the results of Tasks 3 and 4 in an interim report and make a presentation to the project panel. Panel approval will be required before initiating work on Task 5. (5) Develop, validate, and document the methodolgy proposed in Task 4 by applying it to three case study sites selected from the field study sites of Task 3, which have been approved by the panel. (6) Prepare a final report covering Tasks 1–5. The report shall summarize the findings, illustrate the application of the Task 5 methodology, and, where findings are statistically valid, provide methods for predicting the effects on adjacent businesses of restricting left turns, and recommend possible methods to mitigate those effects.

Research is completed on Tasks 1 through 3 and is nearing completion on Task 4.

Project 25-5 FY '92

Remote Sensing and Other Technologies for the Identification and Classification of Wetlands

Research Agency: Normandeau Associates, Inc.
Principal Invest.: Dr. Martin Michener
Effective Date: June 1, 1992
Completion Date: October 31, 1994
Funds: $299,770

Highway project development often requires environmental analyses of several alternative corridors and alignments. These analyses invariably include assessing the impact of projects on wetlands. However, common wetland-identification sources such as National Wetland Inventory (NWI) maps, U.S.G.S. topographical maps, and Soil Conservation Service country soil surveys do not always provide the information necessary for evaluating and comparing potential impacts of alternative highway corridors or alignments during the project development process.

Although federal agencies have agreed on a methodology for identifying and delineating wetlands (Federal Interagency Committee on Wetland Delineation, *Federal Manual for Identifying and Delineating Jurisdictional Wetlands,* 1989—an interagency cooperative publication, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S.D.A. Soil Conservation Service, Washington, D.C.), extensive field investigations to identify, classify, and locate wetlands in sufficient detail within project corridors and alignments are costly and time consuming. Many environmental issues, including wetlands, must be analyzed to reduce the number of alternative corridors or alignments under consideration and to eventually justify requests for the necessary regulatory permits on the final alignment.

There are no readily available methods for efficiently and effectively identifying, classifying, and locating wetlands within corridors and alignments beyond the detail and accuracy of NWI maps. Consequently, there is a need to assess the application of remote sensing technologies to the various stages of project development. An evaluation of technologies and geographical information systems in combination with other existing information resources will be required.

The objectives of this project are to: (1) define *methodologies* suitable for cost effective and timely identification, classification, and location of wetlands required to support decisions throughout the highway project development process; and (2) evaluate *technologies* in terms of cost, procedures, personnel, practicality, application, and accuracy for applying the methodologies.

The applicability of each methodology and associated technologies will depend on the accuracy required at various stages of project development, the cost, and the statistical significance and confidence of the necessary measurements. Application of the methods and technologies also will be based on consideration of their suitability and applicability to various geographic regions, wetland sizes, and classification detail within the Fish and Wildlife Service system (*Classification of Wetlands and Deepwater Habitats of the United States,* Cowardin et al., Washington, D.C., December 1979).

These project objectives will be accomplished in two phases and will require at least the following tasks:

Phase I

Task 1 Information Search. Conduct a comprehensive literature search to locate, assemble, and analyze applicable information. Identify and analyze on-going related research and applications. Sources for this information will include, but are not limited to, computerized research information services, universities, state and federal transportation and natural resource agencies, environmental and engineering consultants, and industries, such as utility companies.

Task 2 Interview Plan. Based on the results of Task 1, identify and select application managers and research project leaders for follow-up interviews. A list of suitable questions will need to be developed for the interviews to obtain details on the various methodologies and technologies. Within 3 months of contract initiation, a summary report of Tasks 1 and 2 will be submitted for NCHRP approval and authorization to proceed with subsequent tasks.

Task 3 Interviews. Perform follow-up interviews.

Task 4 Phase I Final Report. Synthesize and evaluate the information acquired under the previous tasks, fully describing the recommended methodologies and technologies, and develop the Task 5 field-testing program.

Phase II

Task 5 Field Tests. Test the applicability and accuracy of the recommended technologies to implement the various methods identified in Phase I. Field tests will be verified by comparing the results of field tests to actual detailed wetland identifications and delineations using both the Federal Manual for Identifying and Delineating Jurisdictional Wetlands and the Fish and Wildlife Service classification system. Each technology will be evaluated to satisfy the terms of Objective 2.

Task 6 Preliminary Outline. Submit a detailed outline of the Phase II final report for approval by the NCHRP.

Task 7 Phase II Final Report. Fully document the Phase II effort. Based on the results of Task 5, modify and refine the recommendations of Task 4, as appropriate; and provide information that will allow users to determine the suitability of the methodologies and their associated technologies for implementation within various stages of the highway-development process. The information shall include the cost and performance characteristics that were evaluated in Task 5, presented in the form of suitable graphics, matrices, illustrations, and tables. Sufficient detail on the technical procedures must be provided so that the procedures can be duplicated.

Phase I is complete and the Phase I report is available for loan. A portion of Phase II has commenced that is designed to match appropriate techniques with requirements of the various steps in the project development process. If successfully done, the resulting matrix between techniques and the project development steps will be detailed.

Project 25-6 FY '93

Intersection Air Quality Modeling

Research Agency: Systems Applications International
Principal Invest.: Dr. Robert G. Ireson

Effective Date: February 1, 1993
Completion Date: January 31, 1996
Funds: $2,500,000 (Based on NCHRP allocation of $1,050,000 and additional funding from the Federal Highway Administration for $1,450,000.)

Passage of the Clean Air Act Amendments of 1990 requires transportation agencies to assure that their actions do not create or exacerbate violations of ambient air quality standards. For carbon monoxide, these actions must also reduce the severity and number of existing violations. Projects that do not conform cannot proceed. To demonstrate conformance with carbon monoxide (CO) standards, computer models are used to predict concentrations at "hot spot" locations either directly or indirectly affected by a project. Because CO concentrations tend to be highest near areas of heavy traffic congestion, signalized intersections in urban and suburban areas are often the focus of this modeling effort.

There are many fundamental questions regarding current methods for modeling CO concentrations near intersections. For instance, do vehicle emissions need to be resolved by discreet modes of operation (i.e., cruise, acceleration, deceleration, and idle) or are estimated emissions based on average speed accurate and sensitive enough? Are dispersion theories and empirical formulations that are derived from data associated with rural conditions and free-flow traffic appropriate for use near suburban and urban intersections? What traffic variables are needed to drive the emissions and dispersion components of the modeling process?

The lack of compatibility between traffic, emissions, and dispersion models is another difficulty inherent in current methods. These models have evolved separately over time with the result that the outputs of one model may not be compatible with the inputs of the next. Users need a fully integrated package of models to be able to address intersection air quality problems efficiently. Only when the traffic, emissions, and dispersion components are linked together can mitigating strategies involving design and operational modifications be tested interactively.

A better understanding of emissions, dispersion, traffic, and their interrelationships is needed for more accurate predictions of CO concentrations at intersections. The research must be national in scope and be coordinated with other relevant ongoing efforts.

The objectives of this research are to: (1) evaluate information on intersection carbon monoxide concentrations and the pattern of monitored violations, the significance of modal emissions, and the current state of the practice in carbon monoxide intersection modeling; (2) assess the suitability of existing intersection air quality models (emissions, dispersion, and traffic components); and (3) develop an improved integrated model and a computer program for the air quality assessments of intersections at urban and suburban locations.

The accomplishment of these objectives will require the completion of the following tasks:

PHASE I—Problem Assessment

Task 1. Current practice—A national database shall be developed for monitored carbon monoxide violations in areas that are currently designated as nonattainment. The database will include CO concentrations and concurrent, relevant data from nearby sources on traffic, meteorology, and background CO levels. Using available EPA and state air quality agency monitoring records, concentration patterns will be evaluated to identify and document factors and conditions that are present when elevated readings and violations of the standard occur. These evaluations will also include the relationship between high 1-hour and 8-hour averages and between areawide and "hot spot" concentration patterns. Particular attention should be paid to evaluating sites that are near signalized intersections and have substantial historical records that could be used to accomplish subsequent tasks under Phase II. An interim report will be prepared to document the information and insights gained from this task. The report will also include the current state of practice on carbon monoxide intersection modeling as done by state air quality, state transportation, and other appropriate agencies. The interim report will be submitted within 6 months for review and approval by the NCHRP.

Task 2. Modal Emission Data—Obtain all available data on modal emissions (i.e., emissions released during the cruise, acceleration, deceleration, and idle operating modes) and vehicle performance at intersections. At least two such databases are known: EPA's Office of Mobile Sources and the California Air Resources Board. These and other databases shall be studied to evaluate the differences in emissions during various modes of vehicle operation and the relationship of modal emissions to average speed-adjusted emissions. Any available information on modal emissions models shall be included.

Task 3. Site-Monitoring and Evaluation Plan—Prepare a site-monitoring plan, which will be executed under Task 4, to obtain new data for evaluating existing air quality models and for developing new or modified models. The site-monitoring plan shall include, as a minimum: the number, type, and location of sites; the necessary permission to use sites for monitoring purposes; the schedule and duration of the monitoring period; the location and type of equipment (such as that needed to obtain data on the meteorology, existing and background CO concentration, traffic and vehicle performance characteristics, and vehicle emissions); and costs. Protocols will be developed and included that describe the techniques for the assessment required under *Task 5.* The site-monitoring plan, protocol, and the results of Task 2 will be submitted in a second interim report. Initiation of Phase II will be contingent on the approval of the second interim report.

PHASE II—Site Monitoring and Evaluation

Task 4. Monitoring—Monitor a representative number of suburban and urban intersections, geographically distributed and covering a variety of congestion, operation, and geometric conditions. The monitoring program will provide information on the validity of dispersion mechanisms contained in existing models, the proper location of receptors, and the importance of modal emissions in intersection modeling. Multi-probe CO monitoring will be installed to get a detailed picture of CO concentration patterns. Multiple meteorological measurements will be obtained to characterize the meteorology of the site. It is especially important to accurately describe the wind field and the vertical distribution of CO concentrations near the intersections where idle and acceleration emissions occur and at mid-block where cruise emissions predominate. Atmospheric stability should be determined by on-site measurement. Depending on the outcome of Task 2, it may be necessary to obtain more refined measurements of "in-use" modal emissions and atmospheric dispersion. For example, this could involve remote sensing of carbon monoxide, vehicle(s) equipped to emit a tracer gas, or mass balance determinations using the vertical distribution of CO concentrations near the intersection and mid-block. Traffic data will be collected concurrently with the air quality and meteorological data. This will allow the determination of the traffic parameters more important in establishing air quality levels, including delay times, acceleration rate, overall speed profile, traffic mix, traffic volumes, signal timing, and percentage of cold starts.

Task 5. Data Analysis and Assessment—Synthesize and analyze the data collected in Task 4. The theory, principles, and formulation of existing models will be assessed for consistency with the collected data. The suitability of current theory, principles, and formulations to characterize carbon monoxide concentrations at intersections will be evaluated. As appropriate, improvements or adjustments will be recommended to current theory and formulations to more closely simulate observed air quality levels. In the event that the data do not support current theory and formulations in suburban or urban locations, a new methodology will be recommended. A third interim report will be prepared to document Phase II, including the assessments of existing models and recommendations for any changes. Initiation of Phase III will be contingent on the approval of this third interim report.

PHASE III—Model Development

Task 6. Integrated Air Quality Intersection Computer Model—Develop an integrated (emissions dispersion, and traffic) computer model that is PC-based, IBM compatible, and user friendly. This integrated model will be based on modified existing models or, if needed, will be newly created. The dispersion component of this model may take the form of a Gaussian "puff" or numerical simulation as opposed to the current steady-state Gaussian formulation. The model must include screening techniques to assess the degree of severity of existing intersection conditions and to address the question of 1-hour versus 8-hour CO concentrations. The end product of this task shall be an improved intersection air quality model.

Task 7. User's Guide—Develop a User's Guide with adequate documentation and examples so that an individual unfamiliar with transportation air quality modeling could successfully run the model. The documentation shall also include sensitivity analyses, recommended worst-case meteorological conditions, and options for mitigation analyses.

Task 8. Final Report—Prepare a final report that documents the entire research effort, including the Task 7 User's Guide. Software documentation, including the source code of the operational model and the various databases created throughout the research effort, will be submitted with the report. All computer programs and databases will be in the public domain.

Phase I is nearing completion. Reports from Tasks 1, 2, and 4 are being reviewed by the NCHRP and should be available in early 1994. Discussions about Phase II are occurring between the contract research agency and the NCHRP project panel.

Project 25-7 FY '94

Improving Transportation Data for Mobile Source Emissions Estimates

Research Agency:	The University of Tennessee Research Corporation
Principal Invest.:	Dr. Arun Chatterjee
Effective Date:	December 1, 1993
Completion Date:	February 28, 1995
Funds:	$200,000

The 1990 Clean Air Act Amendments (CAAA) require states to attain and maintain ambient air quality standards. Geographic areas not meeting air quality standards are designated as nonattainment areas and must satisfy certain requirements and deadlines depending on the severity of the air quality problem. Mobile sources, like automobiles and other vehicles, are considered to be a significant component of the nonattainment problem, and consequently, the transportation sector is expected to provide appropriate emissions reductions. Decisions for achieving reductions are based on different levels and types of analyses appropriate to local conditions, such as attainment status, the size and complexity of the area, and the type of pollutants. Also, there are a variety of analysis needs, including, but not limited to, emission-inventory development, transportation-control management (TCM) strategies, "conformity" assessments, and state implementation plan (SIP) development.

To meet these requirements, transportation data are being

and will be used, but frequently in ways not originally intended. This usage results in a lack of "fit" in transportation data inputs into the air quality modeling process. For example, the speed outputs from travel models are subject to significant error, yet they are among the most crucial inputs into the mobile source emissions models, such as the U.S. Environmental Protection Agency's MOBILE 5 model or the California Air Resources Board's EMFAC model.

In addition, air quality modeling often requires transportation data that are difficult to obtain or may not exist. To overcome this problem, default values for transportation data, such as "cold-starts" and vehicle-mix and age-characteristics, are used. Also, the CAAA identifies estimates of vehicle-miles traveled (VMT) as an important component in the attainment of ambient air quality standards, but no accepted technique exists for estimating VMT on local roads. Yet, local roads are assumed to carry one-third of the VMT in an urbanized area, under high-emissions conditions of low speeds and high-idle times. The impacts of these problems on emissions estimates for nonattainment areas with differing characteristics are not well understood.

Because transportation modeling and air quality modeling are dependent on each other, a better understanding of this dependence and the underlying assumptions used in individual modeling processes is needed. Recognizing the prescriptive nature of the types of air quality models that must be used, an initial priority is to examine the impact of transportation data on the estimates from these air quality models and on air quality planning.

The objective of this research is to improve the integration of transportation data with emissions-estimation procedures and air quality planning. Key elements of this integration process include: (1) transportation variables that are available or necessary for developing emissions burdens and other air quality projections, (2) techniques for developing values for these variables, and (3) interrelationships between transportation data and emission rates. The research will critically evaluate these elements, and then identify and prioritize improvements to existing procedures for calculating or estimating transportation data, given existing transportation, emissions, and air quality models.

Accomplishment of this objective will require at least the following tasks. Tasks 1 through 3 need not be done sequentially. (1) *Identify Key Variables by Level and Type of Transportation/Air Quality Analysis.* Identify the factors that dictate how a nonattainment area must structure its level of effort with respect to collecting data and estimating mobile source emissions. Given the requirements of the CAAA, describe the process by which monitoring tools such as the Federal Highway Administration's Highway Performance Monitoring System (HPMS), travel-demand models, emissions models, and air quality models are integrated for air quality purposes. Identify the transportation variables of significance in emissions modeling and air quality planning. Expected variables include speeds, trip ends, cold-starts, vehicle class and age distribution, percent of "super-emitters," and temporal and spatial patterns of VMT; however, additional variables are expected to be identified based on inputs to the MOBILE and EMFAC emission models, as well as other air quality analysis needs. (2) *Evaluate Current Practice and Alternative Approaches.* (a) Describe and evaluate the current state of practice in transportation data development for air quality analyses. Alternative approaches not in practice, but available, shall be included. Information sources may include literature searches, surveys, interviews, existing SIPs, and the National Association of Regional Councils' (NARC) manual for modeling practices for air quality analyses. (b) Investigate the relationships among different model sets and monitoring tools and assess the consistency of data, the approach, and the management of information. Existing databases, models, theories, and methodologies will be evaluated to determine which produce the data and information most suited for use in air quality estimation.

Evaluations will include assumptions made, known correlations of variables and estimates based on currently used data, ease of implementation, and suitability of data format for air quality estimate input. Strengths and weaknesses of each method will be identified. (c) Assess the effect of local, functionally classified road information and varying geographic boundaries on VMT estimates. (d) Assess the use of travel-behavior information taken from travel surveys in making air quality estimations. (3) Conduct Sensitivity and Uncertainty Analyses. Estimate the sensitivity of emissions models to key transportation variables. Uncertainties for each variable will be quantified for the various levels of spatial and temporal aggregation required for various regulatory analyses. A qualitative evaluation of the influence of these uncertainties on other air quality models will also be included. (4) *Prepare Final* Report and Establish Priorities for Developing Improvements. The contractor will prepare a report documenting Tasks 1 through 3. The report will include the following: (a) An introductory overview of how the travel, emissions, and air quality models relate to one another, and the most important assumptions and variables. (b) Recommendations of the most appropriate method(s) to be used for the various levels and types of analyses examined. Recommendations will build on and not duplicate the NARC modeling manual. (c) Priorities for improvements to estimation procedures and, if appropriate, the collection methods of needed transportation data. These recommendations shall reflect the expected degree of improvement in emissions estimates and the cost and level of effort required to achieve the improvements. (d) Protocols for implementing and testing high-priority improvements. As appropriate, software documentation and various databases created throughout the research effort will be submitted with the report. All computer programs and databases will be in the public domain.

Project 25-8 FY '94

Impact of Highway Capacity Improvements on Air Quality and Energy Consumption

Research Agency: Transportation Research Board
Principal Invest.: Robert E. Skinner & Nancy Humphrey
Effective Date: March 1, 1993
Completion Date: August 1, 1994
Funds: $100,000

It is generally agreed that highway capacity improvements reduce most motor vehicle emissions in the short run by increasing speeds and reducing start-and-stop driving. However, questions have increasingly been raised about the longer term effects of capacity improvements on air quality as well as energy consumption. This issue is already at the center of legal and environmental challenges to some controversial highway projects, and such challenges are likely to be more common as the stricter requirements of the Clean Air Act Amendments of 1990 are implemented. An objective examination of the issue could assist decision making by judicial and executive agencies by narrowing the debate and possibly laying the groundwork for national guidelines for the roles that capacity improvements can play in (a) meeting air quality standards and (b) assessing the implications of such improvements on energy consumption.

An expert committee, convened by the National Research Council and the Transportation Research Board, will conduct critical reviews of existing research and land use/transportation/air quality analyses for selected urban areas. The committee will produce an authoritative report that summarizes what is now known (and not known) about the relationships between highway capacity improvements, air quality, and energy consumption, and discusses the implications of this knowledge for air quality and transportation plans, energy demand forecasts, planning, procedures, and research. The results of this study will be helpful in reaching decisions that now must be made with inadequate information.

NCHRP contribution to a multisponsored TRB policy study is estimated at $450,000.

Project 25-9 FY '94

Environmental Impact of Construction and Repair Materials on Surface and Ground Waters

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (18 months)
Completion Date:
Funds: $200,000

A number of uncertainties exist regarding the effects on ecosystems and human health of constituents that migrate from the roadway through surface water and groundwater. These constituents originate from materials used in construction and repair of the roadway, construction procedures, vehicular operations, maintenance procedures, and atmospheric deposition.

Considerable research has been conducted in the area of water-quality impacts from highway and vehicle operations, maintenance practices, and atmospheric deposition. There is an ongoing FHWA study, based on past research in this area, that will synthesize relevant information on the impacts of highway runoff on receiving water quality. Future research is planned (FHWA's proposed High Priority Area program, "Highways and Water Resources—Improving the Prediction of Impacts and the Effectiveness of Mitigation Techniques") that will extend these efforts to characterize the chemical, physical, and biological contaminants in the roadway stormwater runoff and their impacts on receiving waters.

Historically, construction and repair materials have been viewed as being innocuous and hence not of concern to environmental quality. Currently there is a perception that some of these materials may pose an environmental concern. Furthermore, a variety of recycled and waste materials are being considered for use as construction and repair materials, thereby increasing the number of nontraditional materials in contact with surface water and groundwater.

This research project will concentrate on identifying potentially mobile constituents from highway construction and repair materials and their possible impacts on surface water and groundwater. Materials used in construction and repair that are likely to come into contact with the surface water and groundwater include: asphalt, concrete additives, metals, grouts, plastics/synthetics, shredded rubber tires, Styrofoam, creosote and other timber preservatives, and others. Explicitly excluded from consideration in this project are constituents originating from construction processes, vehicular operations, maintenance operations, and atmospheric deposition.

The ultimate objective of this research is to develop a validated methodology for assessing the environmental impact of highway construction and repair materials on surface water and groundwater, and to apply the methodology to a spectrum of materials in representative environments. Accomplishment of this objective will involve several phases. This phase of the research will develop a proposed methodology for assessing the environmental impact of highway construction and repair materials on surface water and groundwater. Additionally, limited testing toward validation will be conducted.

The research will include as a minimum the following tasks:

Task 1. Identify highway construction and repair materials that may have constituents that could become mobile via chemical, biological, and physical processes through the highway operation and within the operational environment. These constituents may have the potential to negatively 25-

9, page 2 impact surface water and groundwater—thereby affecting human health and aquatic ecosystems.

Task 2. Propose a methodology to assess the potential of highway construction and repair materials to release mobile constituents in the roadway environment. In addition, the methodology must identify the field conditions that affect the transport and persistence of these constituents. Identify sampling, testing, and modeling procedures that can document the distance these constituents can migrate in the roadway environment.

Task 3. Within 6 months after the start of the contract, submit an Interim Report that describes the construction and repair materials identified in Task 1 and the methodology developed in Task 2. The Interim Report will include a work plan for conducting a limited testing program to evaluate the methodology.

Task 4. Conduct a testing program to evaluate the proposed methodology, recommend refinements, and develop a plan for validation of the methodology. The plan should include a proposed budget, timetable, and priority list of materials to be tested.

Task 5. Propose a conceptual model for estimating the portion of contaminants in highway runoff and groundwater that originates from construction and repair materials. (Note: NCHRP anticipates that this task will not exceed 5% of the budget.)

Task 6. Prepare a final report detailing the entire research effort.

Project 25-10 FY '94

Estimating the Indirect Effects of Proposed Transportation Projects

Research Agency:	Louis Berger & Associates, Inc.
Principal Invest.:	Nicholas Masucci
Effective Date:	December 1, 1993
Completion Date:	May 31, 1995
Funds:	$300,000

Transportation projects have both direct and indirect effects on the environments in which they are located. The National Environmental Protection Act (NEPA) and its implementing regulations mandate the assessment and disclosure of reasonably foreseeable effects of transportation projects. As a result, procedures have been established to identify and estimate many of the direct effects of projects. However, the indirect effects are both harder to identify and more difficult to assess. These indirect effects include, but are not limited to, changes in social and economic conditions, natural resources, cultural/historical resources, accessibility, induced traffic, noise levels, and air quality.

The NEPA Implementing Regulations (40 CFR 1502.16 (b)) require the scientific analysis of indirect effects and their significance as part of the environmental impact review process. Federal Highway Administration (FHWA) regulations do not specifically address the analysis of indirect effects, but refer to the NEPA Implementing Regulations. However, FHWA Technical Advisory (T 6640.8A, "Guidance for Preparing and Processing Environmental Section 4(F) Documents") more specifically requires the evaluation of indirect social, economic, and environmental effects. Other federal and state agencies also have requirements related to indirect effects that must be addressed as well.

State departments of transportation and other agencies have expressed a need for guidance in estimating the indirect effects of proposed projects. Hence, research is needed to define indirect effects of proposed projects, to develop techniques for identifying, understanding, describing, and estimating these effects, and to prepare guidelines to facilitate the analysis of indirect effects of transportation projects.

The objective of this research is to develop an analysis framework and supporting methods to facilitate identifying, understanding, describing, and evaluating indirect effects of transportation projects. Specifically, this research will 1) establish a working definition of indirect effects, which includes an interpretation of "reasonably foreseeable" effects; 2) identify and describe the causal relationships among projects, indirect effects, and the conditions under which they are likely to occur; 3) identify and assess the adequacy of current procedures and techniques for estimating indirect effects; and 4) recommend a framework for reviewing transportation projects for indirect effects, with appropriate processes for separating project-induced effects from those that would occur without the project. The research is expected to produce a set of guidelines for use in analyzing the indirect effects of transportation projects.

To accomplish the project objective, the following tasks are envisioned:

Task 1. Establish a working definition of indirect effects of transportation projects. This definition should be based on the NEPA regulations, the literature, and contacts with agencies involved in transportation planning and development, and environmental monitoring and regulation. A critical element will be to establish guidance for transportation agencies in determining the spatial and temporal bounds of a "reasonably foreseeable" future. Proposals should describe the process that will be used to undertake this task.

Task 2. Catalog adverse, beneficial, and nonimpacting indirect effects associated with different types of transportation projects. The indirect effects need to be categorized to reflect the differences in scale between system-wide transportation plans and specific projects. Identify and describe the causal relationships among projects, indirect effects, and the conditions under which they are likely to occur. In this effort, the procedures and techniques that have been applied to estimate indirect effects should be cataloged. Information should be gathered from published literature, environmental documents, and contacts with transportation, regulatory, academic, and other organizations.

Task 3. Evaluate the procedures and techniques for estimating the indirect effects identified in the Task 2. Document

the sources of data, the analysis techniques or methods used, and the applicability of the methods. Critique the techniques and procedures based on practicality, reliability, cost, and acceptability. Conceptualize other tools to aid the analysis process and describe these in sufficient detail to permit their development in Task 8 or subsequent research.

Task 4. Propose a preliminary framework for the systematic analysis of indirect effects of transportation projects. The framework should incorporate processes (guidance) for establishing the spatial and temporal limits of project impacts and for separating project-induced effects from those that would have occurred without the project. The framework should reflect the roles of different agencies in the analysis and mitigation of indirect effects. Develop checklists, flow charts, or other tools to facilitate the application of the framework. The proposal should include the proposer's current thinking on the nature of the framework and examples of how it would be applied.

Task 5. Prepare a draft interim report describing (1) the established working definition for indirect effects; (2) the proposed framework, supporting rationale, and associated checklists, flow charts, or other aids; (3) the techniques and procedures for estimating indirect effects to be used within the framework; (4) the recommendations for tools that need to be obtained or developed to support the analysis process (i.e., "toolbox"); (5) the types of case studies that would be used to demonstrate the applicability of the process; and (6) the plans for packaging the framework and associated methodologies into a set of guidelines. The interim report should also indicate areas where the analysis of indirect effects is not possible without further research. The panel will review the interim report and determine whether there is merit in proceeding to actual development of the guidelines. The contractor will be expected to participate in an interim meeting with the project panel to set directions for completion of study. The contractor will not proceed with Task 6 without NCHRP approval.

Task 6. Prepare a revised version of the interim report reflecting the comments of the panel. Provide 50 copies of this version for an extended review of the proposed analysis framework by professionals in the transportation and environmental fields. The NCHRP will distribute the report and compile all review comments received. The contractor will review the comments and recommend changes to the analysis framework and supporting methodologies. The contractor should be prepared to meet with the panel to determine which changes will be incorporated into the proposed guidelines.

Task 7. Finalize the framework and associated procedures and techniques as approved in Task 6. Compile draft guidelines documenting the various indirect effects, indicating when they should be estimated, and describing the techniques that can be used to estimate them. Develop tools and aids approved by the project panel and package the guidelines into a document that will facilitate their use.

Task 8. Demonstrate the applicability of the analysis framework by undertaking several case studies. Select case studies that represent various types of transportation improvements and environmental situations (e.g., urban, suburban, rural areas). Estimate indirect effects using guidelines developed in Task 7 by applying them to actual projects approved by the project panel. Modify the draft guidelines based on the results of this effort and project panel review.

Task 9. Prepare a final report documenting the entire research effort. The final report should include (1) an executive summary describing indirect effects, the analysis framework, and the procedures for estimating indirect effects; (2) a revised set of guidelines for analyzing indirect effects; (3) documentation for any items to be included in the "toolbox"; (4) other necessary supporting materials; (5) a recommended implementation plan for moving the results of this research into practice; and (6) a summary of future research needs.

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