NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS

December 31, 1991

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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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
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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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MAILING ADDRESS:

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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 highway planning research (HPR) funds. These funds presently make available a cooperative pool of about $8.0 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 some 753 members on these panels coming from 51 States, the District of Columbia, Puerto Rico, Canada, and Sweden.

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 7 to 10 new problems, each with funding usually ranging between $150,000 and $300,000 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 188 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.

In 1990 AASHTO referred the thirtieth program (FY '92) of research problems. From all programs through FY '92, 542 research contracts have resulted (Table 3), totaling some $103.7 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 thirty-first program (FY '93) was formulated in September 1991 by the Standing Committee on Research. Proposals will be solicited in March 1992. AASHTO's initial steps toward development of the thirty-second research program (FY '94) were taken in October 1991.

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 1½ percent federal-aid highway planning and research (HPR) funds. From these contributions a cooperative pool of about $8.3 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 '92 program were scheduled to begin in December 1991.

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.

NCHRP RESEARCH FIELDS AND AREAS

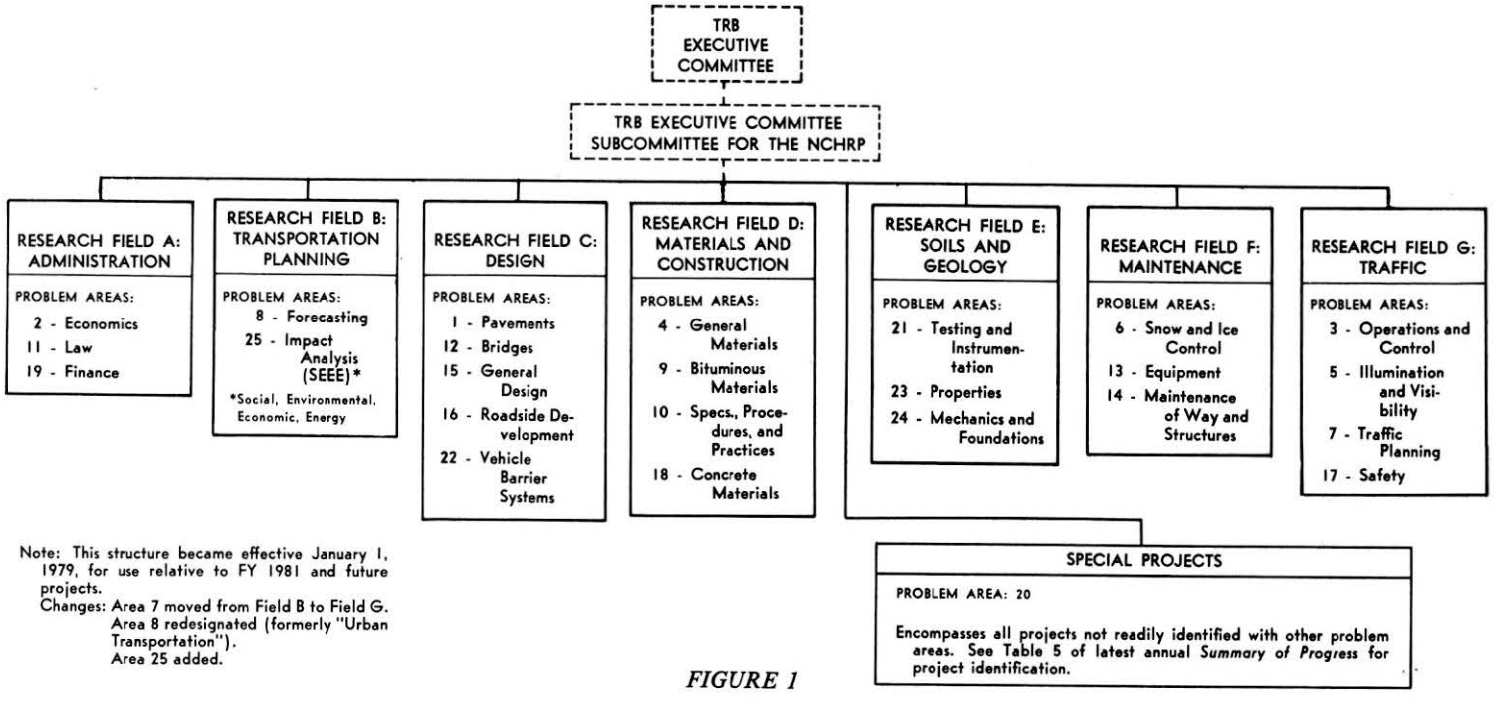

FIGURE 1

TABLE 1
DISTRIBUTION OF PROJECTS WITH RESPECT TO GENERALIZED SUBJECT AREAS

NO. OF PROJECTS	PERCENT OF FUNDS	GENERALIZED SUBJECT AREAS
59	9.5	Socio-economic and environmental issues
65	12.6	Urban issues
18	3.0	Multimodal issues
91	14.6	Safety and accident prevention
20	3.4	Legal studies
37	14.9	Special projects (including in-house)
34	4.9	Improved materials quality and performance
37	5.8	Highway maintenance
76	13.0	Specifications, tests, and construction control
105	18.3	Structural design and performance

In terms of generalized subject areas, the distribution of all projects through FY 1992 is shown in Table 1.

Each project is assigned to a panel consisting of outstanding 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 2, 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 2,000 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 3. 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
DISTRIBUTION OF PROJECT PANEL AND COMMITTEE MEMBERSHIP WITH RESPECT TO AFFILIATION

AFFILIATION	NO. OF MEMBERS	POSITIONS INVOLVED
State highway and transportation departments	336	388
Federal Highway Administration*	54	70
Special transportation and other governmental agencies	73	79
Educational institutions	117	141
Research institutes	4	3
Industry, consultants, and trade associations	158	181
Professional societies and service organizations	11	13
All	753	875

* Does not include liaison representatives

TABLE 3

AGENCY DISTRIBUTION OF FY '63 THROUGH FY '92 PROJECTS

TYPE OF AGENCY	CONTRACTS NO.	%
Educational institutions	189	34
Research institutes	75	14
Industry, consultants, and trade associations	258	47
Professional societies and service organizations	19	4
State highway and transportation departments	5	<1
Special transportation and other governmental agencies	3	<1
All	549	100

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 30 fiscal year programs conducted to date are listed in Table 4.

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 17—8 professional, 9 support. In-depth surveillance by projects engineers 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 re-

sponsive 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 5, 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.

AWARD-WINNING RESEARCH UNDER NCHRP

Several projects have been honored to date as outstanding contributions to the field of highway safety and have received Metropolitan Life Awards for Research in Accident Prevention from the National Safety Council. They are:

- NCHRP Project 1-7, "Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces." In 1968, this project, reported as *NCHRP Report 37,* "Tentative Skid-Resistance Requirements for Main Rural Highways," received the Award of Merit ($500).

- NCHRP Project 3-8, "Factors Influencing Safety at Highway-Rail Grade Crossings." In 1969, this project, reported as *NCHRP Report 50,* "Factors Influencing Safety at Highway-Rail Grade Crossings," received top honors—the Award of Honor ($1,000).

- NCHRP Project 2-3, "Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements." Also in 1969, this project, reported as *NCHRP Report 47,* "Accident Rates as Related to Design Elements of Rural Highways," placed second and received the Award of Merit ($500).

Other projects prominent in various other classes of awards are:

- NCHRP Project 20-7, Task 2, "The Relation of Side Slope Design to Highway Safety." In 1977, Eugene D. Marquis and Graeme D. Weaver shared the 1977 Arthur M. Wellington Prize of the American Society of Civil Engineers for their paper, "Roadside Slope Design for Safety," which was based on the research reported in *NCHRP Report 158,* "Selection of Safe Roadside Cross Sections."

- NCHRP Project 20-3, "Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control." In 1969, a paper based on this project received Honorable Mention under the Past President's Award, Institute of Traffic Engineers.

- NCHRP Project 9-1, "Asphalt Durability and Its Relation to Pavement Performance." In 1969, a paper based on this project, reported in *NCHRP Report 67,* "Relation of Asphalt Rheological Properties to Pavement Durability," received the W. J. Emmons Annual Award of the Association of Asphalt Paving Technologists as the best paper at the annual meeting.

- NCHRP Project 5-8, "Warrants for Highway Lighting." In 1973, a paper based on this project, reported in *NCHRP Report 152,* "Warrants for Highway Lighting," received the Highway Research Board Award as the most outstanding paper presented at the Board's Annual Meeting.

- NCHRP Project 12-7, "Effects of Weldments on Fatigue Strength of Steel Beams." In 1977, the Principal Investigator, Professor John W. Fisher, received the T. R. Higgins Award from the American Institute of Steel Construction as author of *NCHRP Report 147,* "Fatigue Strength of Steel Beams with Welded Stiffeners."

- NCHRP Project 12-12, "Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings." In 1979, the Principal Investigators, Karl H. Klippstein and Charles G. Schilling, were co-recipients of the Arthur M. Wellington Prize from the American Society of Civil Engineers for their paper, "Fatigue of Steel Beams by Simulated Bridge Traffic," published in the *Journal of the Structural Division,* August 1977. The paper was based on Project 12-12.

- NCHRP Project 20-9, "Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation." The Principal Investigator, Mr. Jon E. Burkhardt, received the 1980 Pyke Johnson Award from the Transportation Research Board as author of the paper "Residential Dislocation: Costs and Consequences."

- NCHRP Project 1-17, "Guidelines for Recycling Pavement Materials." In 1981, a paper based on this project, reported in *NCHRP Report 224,* "Guidelines for Recycling Pavement Materials," received the W. J. Emmons award for the best technical paper at the annual meeting of the Association of Asphalt Paving Technologists.

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 transportation 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 4
SUMMARY OF STATUS THROUGH DECEMBER 31, 1991 FOR FY '63 THROUGH FY '92 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	425,000
	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*
2-4	The Value of Highway Travel Time, Comfort, Convenience, and Uniform Driving Speed	Texas A & M	77,100*

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 Rep. 7; final rep. 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—Rep. 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—Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	1-15
6/3/74	10/31/81	Completed—Rep. 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	Report in review stage	1-25(1)
2/6/87	6/30/92	Research in progress	1-26
3/1/89	8/31/91	Completed—Report not publ.; for avail., see writeup in latest Summary of Progress	1-27
4/15/90	1/14/93	Research in progress	1-28
6/1/63	11/30/67	Completed—Rep. 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
6/1/63	8/31/66	Completed—Published as NCHRP Report 33	2-4

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWO (*Continued*)		
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 Evaluation 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
2-18	Research Strategies for Improving Highway User Cost-Estimating Methodologies	Hickling Corp	150,000
	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*
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*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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—Rep. 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 rep. publ. as NCHRP Report 307; Phase II rep. 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—Rep. not publ.; for avail., see project writeup in latest Summary of Progress	2-17(2)
11/1/91	6/30/93	Research in progress	2-17(3)
10/14/91	7/16/93	Research in progress	2-17(4)
9/15/91	3/15/93	Research in progress	2-17(5)
1/2/91	10/31/92	Research in progress	2-18
2/15/63	2/29/64	Completed—Report included in Phase II report	3-1
7/2/64	2/28/66	Completed—Rep. 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—Rep. 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
11/1/69	4/30/71	Completed—Rep. 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—Rep. 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)

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA THREE (*Continued*)		
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
3-39	Evaluation and Calibration Procedures for Weigh-In-Motion Systems	Texas A&M	398,500
3-40	Single Point Urban Interchange Design and Operations Analysis	Texas A&M	250,000
3-41	Procedure for Determining 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	—	350,000
	AREA FOUR: MATERIALS AND CONSTRUCTION—GENERAL MATERIALS		
4-1	Development of Appropriate 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*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
5/1/75	4/15/77	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	3-18(3)
7/21/77	11/20/80	Completed—Rep. 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—Rep. 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—Rep. 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—Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	3-23
9/1/74	4/30/77	Completed—Rep. 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—Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	3-28
5/1/80	2/28/83	Completed—Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	3-28(2)
7/1/83	3/31/86	Completed—Rep. 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—Rep. not publ.; avail. on loan basis	3-32
6/1/85	4/30/90	Completed—Rep. not publ., for avail., see project writeup	3-33
11/1/85	9/30/88	Completed—Published as NCHRP Report 303	3-34
6/1/86	5/31/89	Completed—Rep. not publ.; agency rep. avail. for loan	3-35
2/16/87	10/31/91	Final report avail. on a loan basis	3-36
7/1/90	6/30/93	Phase I report in review stage; Phase II research in progress	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	6/30/92	Research in progress	
10/1/87	2/1/91	Completed—Report not received	3-38(4)
4/1/88	6/30/90	Completed—Published as NCHRP Report 330	3-38(5)
5/15/88	2/28/91	Report in review stage	3-38(6)
5/15/89	4/30/91	Completed—Report in editorial and publication process	3-38(7)
3/1/88	10/30/91	Report in review stage	3-39
5/1/89	11/30/91	Report in editorial and publication process	3-40
11/15/89	4/15/92	Research in progress	3-41
5/1/91	5/1/94	Research in progress	3-42
1/15/91	4/15/94	Research in progress	3-43
30 months		Contract pending	3-44
6/1/63	10/31/66	Completed—Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	4-5

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA FOUR (*Continued*)		
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	—	300,000
	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*
5-2(2)	Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort	Ohio State U	21,530* 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	203,821
5-12	Requirements for Application of Light Emitting Diodes (LEDs) to Traffic Control Signals	—	250,000
	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*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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—Rep. 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—Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	4-13
4/1/78	9/30/79	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	4-13A
1/1/78	12/31/81	Completed—Rep. 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—Rep. not publ.; agency rep. avail. for loan; sum. to be publ. in Research Results Digest	4-16
1/7/85	10/31/87	Completed—Published as NCHRP Report 305	4-17
30 months		Contract pending	4-18
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—Rep. not publ.; for avail., see Summary of Progress Through 1988	5-5A
9/1/71	12/31/74	Completed—Rep. 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	Phases I & II completed; reports not publ.; avail. on a loan basis	5-10
2/15/89	8/31/91	Report in review stage	5-11
30 months		In developmental stage	5-12
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—Rep. 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—Rep. 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

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA SIX (*Continued*)		
6-9	Potential Accelerating 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	—	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*
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*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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		Contract pending	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—Rep. 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	4/30/92	Research in progress	7-12
24 months		Contract pending	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—Rep. 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
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 rep. 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 rep. 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—Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	8-15
10/1/77	3/31/80	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	8-15A
1/1/76	12/31/80	Completed—Publ. as NCHRP Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	8-19

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA EIGHT (*Continued*)		
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	180,000*
8-29	Travel Estimation Techniques for Urban Planning	Barton-Aschman	300,000
	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*
	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*
10-4	Rapid Test Methods for Field Control of Construction	Clemson U	30,000* 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*
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* 150,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
1/2/78	7/31/80	Completed—Rep. 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 rep. 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—Rep. 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	8/15/92	Research in progress	8-29
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—Rep. 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)
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	
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—Rep. 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—Rep. 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—Rep. not publ.; report avail. on a loan basis from NCHRP	
4/2/79	5/1/81	Completed—Published as NCHRP Report 237	10-14
4/1/80	9/30/82	Completed—Rep. 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 rep. publ. as NCHRP Report 274; Phase II interim report avail. for loan	10-17
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	

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TEN (*Continued*)		
10-20A	High-Load, Multi-Rotational Bridge Bearings: Design, Materials, and Construction	U of Washington	250,000
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 Wtwys Exp Sta	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	490,000
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
	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*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
8/21/89	2/28/92	Research in progress	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—Rep. not publ.; summary of findings publ. in RRD 169; 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—Rep. not publ.; sum. to be publ. in Research Results Digest	10-25A
6/15/83	9/14/84	Completed—Rep. 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	1/30/92	Research in progress	10-29
1/6/86	9/29/86	Completed—Rep. not publ., for avail., see Summary of Progress Through 1988	10-30(1)
1/20/86	10/3/86	Completed—Rep. not publ., for avail., see Summary of Progress Through 1988	10-30(2)
7/1/87	8/31/90	Report in review stage	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	3/31/91	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	Phase I completed—Published as NCHRP Report 317; Phase II research in progress	10-34
11/1/87	4/30/91	Report in revision stage	10-35
5/2/88	3/31/92	Research in progress	10-36
5/1/91	1/31/94	Research in progress	10-37
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—Rep. 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—Rep. 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—Rep. 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—Rep. 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

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWELVE (*Continued*)		
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*
			200,000*
12-8	Bridge Rail Service Requirements as a Basis for Design Criteria	Texas A & M	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*
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	58,520*
		Shanafelt/Horn	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	228,800
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
12-27	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 Systems Software	—	350,000
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	200,000
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*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
12/15/65	3/31/68	Completed—Rep. 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—Rep. 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—Rep. 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	Report in revision stage	12-15(5)
9/1/74	11/30/77	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	12-16
11/15/76	4/30/78	Completed—Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	12-18
2/1/84	1/3/86	Completed—Report not published	12-18A
1/1/78	12/31/80	Completed—Rep. 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
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	1/3/92	Completed—Phase I report distributed to sponsor. Phase II research in progress	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—Rep. not publ.; for avail., see proj. writeup in latest Sum. of Prog.	12-26
8/22/88	10/31/90	Report in editorial and publication process	
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—Report not published	12-28(2)
18 months		Contract pending	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	Report not received	12-28(11)
9/1/87	5/30/90	Report in editorial and publication process	12-28(12)
10/4/87	9/30/89	Completed—Rep. not publ.; agency rep. avail. for loan	12-28(13)
12/17/90	6/16/93	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—Rep. not publ.; agency rep. avail. for loan	12-30
9/1/87	2/28/91	Report in review stage	12-31
4/1/86	5/15/87	Completed—Published as NCHRP Report 297	12-32

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWELVE (*Continued*)		
12-33	Development of a Comprehensive Bridge Specification and Commentary	Modjeski and Masters	797,147
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	—	350,000
	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	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities	Byrd, Tallamy et al	200,000*
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	250,000
14-9(2)	Incorporation of Maintenance Considerations in Highway Design	Daniel, Mann et al	190,000
14-9(3)	Maintenance Contracting	Bergstralh-Shaw et al	150,000
14-9(4)	Role of Highway Maintenance in Integrated Management Systems	Cambridge System	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	300,000
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	249,360
15-11A	BRI-STARS Maintenance Support and Enhancement	Hydrau-Tech	99,827
15-12	Roadway Widths for Low Traffic Volume Roads	Jack E. Leisch Assoc	250,000
15-13	Long-Term Performance of Geosynthetics in Drainage Applications	GRI—Drexel U	455,240
15-14(1)	Intersection Sight Distance	—	350,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
7/1/88	3/31/92	Research in progress	12-33
9/19/88	12/31/90	Completed—No report	12-33A
9/16/88	3/31/92	Research in progress	12-33B
7/24/89	12/31/91	Research in progress	12-33C
10/19/87	10/18/89	Completed—Rep. not publ.; see proj. writeup in latest Sum. of Prog.	12-34
1/4/88	7/3/89	Completed—Rep. not publ.; see proj. writeup in latest Sum. of Prog.	12-35
4/8/91	7/7/93	Research in progress	12-36
36 months		Contract pending	12-37
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
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—Rep. not received	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	Research in progress	14-8A
6/12/88	6/15/88	Completed—Problem statements developed	14-9
11/15/89	3/16/92	Research in progress	14-9(1)
2/28/90	2/27/92	Report in review stage	14-9(2)
3/12/90	9/11/91	Completed—To be published as NCHRP Report 344	14-9(3)
4/15/91	1/14/93	Research in progress	14-9(4)
5/1/91	7/30/92	Research in progress	14-9(5)
2/1/91	4/30/92	Research in progress	14-9(6)
5/29/89	10/14/92	Phase I published as NCHRP Report 334; Phase II research in progress	14-10
6/1/89	3/31/92	Research in progress	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—Ph. I rep. publ. as NCHRP Rep. 108 Ph. II rep. 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—Rep. 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	11/30/92	Research in progress	15-11A
5/1/89	6/30/92	Report in review stage	15-12
4/1/90	3/31/93	Research in progress	15-13
30 months		Contract pending	15-14(1)

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	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*
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
17-9	Effect of Highway Standards on Safety	—	200,000
	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	195,260*
		National Analysts	83,911*
20-5	Synthesis of Information Related to Highway Problems	TRB	600,000[c]
20-6	Legal Problems Arising out of Highway Programs	TRB	160,000[c]
20-7	Research for AASHTO Standing Committee on Highways		
	Task 1: Development of a Cost-Effectiveness Approach to the Programming of Roadside Safety Improvements	Texas A & M	32,837*
	Task 2: The Relation of Side Slope Design to Highway Safety	Texas A & M	104,088*
	Task 3: Development of an Effective Earth-Berm Vehicle Deflector	Texas A & M	33,973*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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—Rep. 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—Rep. 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
12/16/88	5/15/89	Completed—Published as NCHRP Report 320	17-7
6/1/88	8/31/91	Report in review stage	17-8
21 months		Contract pending	17-9
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—Rep. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-3C
5/15/77	12/31/78	Completed—Spec. 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 6 for topic reports published as NCHRP Syntheses	20-5
11/1/68	[c]	Research in progress: Refer to Tables 7 and 8 for publications	20-6
			20-7
12/2/68	3/31/72	Completed—Published as NCHRP Report 148	(Task 1) 20-7
12/2/68	1/31/74	Completed—Published as NCHRP Report 158	(Task 2) 20-7
12/2/68	3/3/71	Completed—Rep. not publ.; sum. in NCHRP Res. Results Digest 77	(Task 3) 20-7

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY (*Continued*)		
	Task 4: Lateral Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relative to Available Pavement Skid-Resistance Measures	Texas A & M	112,702*
	Task 5: Effect of Curb Geometry and Location	Texas A & M	49,996*
	Task 6: Development of Impact Attenuators Utilizing Waste Materials	Texas A & M	74,852*
	Task 7: Safety at Narrow Bridge Sites	Texas A & M	100,000*
	Task 8: Energy and Transportation Systems	CalDOT	104,440*
	Task 9: Review of Highway Management Studies Co-Sponsored by AASHTO and HUFSAM	Mgmt & Trans Assoc	49,820*
	Task 10: Review of Vehicle Weight/Horsepower Ratio as Related to Passing-Lane Design Criteria	Penn State U	15,493*
	Task 11: Longitudinal Occupancy of Freeways by Utilities	Byrd, Tallamy et al	50,000*
	Task 12: Guidelines for Citizen Participation in Transportation Planning	K. S. Hudson	15,500*
	Task 13: Guidelines for Safety Criteria for Low-Volume Roads	J. C. Glennon	33,226*
	Task 14: A Policy on Geometric Design of Highways and Streets	John F. Holman Co	98,563*
	Task 15: Development of a Simplified Pavement Management System	ARE Inc	103,600*
	Task 16: Regulation of Movement of Hazardous Cargoes	D. M. Baldwin	7,341*
	Task 17: Evaluation of AASHO Road Test Satellite and Environment Studies	Texas A & M	94,402*
	Task 18: Standard Specifications for Highway Bridges	Howard, Needles et al	110,000*
	Task 19: Engineering Aspects of Highway Traffic Safety in an Age of Limited Resources	TRB	25,000*
	Task 20: Vehicle Acceleration and Deceleration Characteristics	U of Michigan	25,000*
	Task 21: Need for Pavement Markings on Low-Volume Roads	J. C. Glennon	25,000*
	Task 22: Encasement of Pipelines Through Highway and Railroad Roadbeds	Byrd, Tallamy et al	20,000*
	Task 23: Contracting Practices and Payment Procedures	Bergstralh-Shaw et al	80,340*
	Task 24: AASHTO Pavement Design Guide	McCullough/Finn	558,200*
	Task 25: STRS Support Task	TRB	52,640*
	Task 26: Research and Development Needs in Construction and Engineering Management	Bergstralh-Shaw et al	25,000*
	Task 27: Relationships Between Vehicle Configurations and Highway Design	TRB	50,593*
	Task 28: AASHTO Guide for Design of Pavement Structures-Training Program	ARE Inc	135,000*
	Task 29: Pavement Roughness and Rideability—Field Evaluation	JMJ Research	—
	Task 30: Manual on Subsurface Investigations	Adrian Pelzner	24,125*
	Task 31: Development of Comprehensive Bridge Specifications and Commentary	Modjeski and Masters	82,492*
	Task 32: Design and Construction Specifications for Segmental Concrete Bridges	Post-Tensioning Inst	74,585*
	Task 33: Study of FHWA Research Program	L. G. Byrd	50,000*
	Task 34: AWS/AASHTO Bridge Welding Code	Warren G. Alexander	50,000
	Task 35: Review of Traffic Signal Intensity Standards	JMJ Research	81,536*
	Task 36: Critical Assessment of Tire Pressure Research	Harry A. Smith	15,000
	Task 37: Development of an Asphalt Paving Handbook	TRB	45,000[d]
	Task 38: AASHTO Guidelines for Pavement Management Systems	ARE Inc	99,989
	Task 39: Revision of the AASHTO Pavement Overlay Design Procedures	Darter & Assoc	75,000
	Task 40: Analytical Support for the Highway Research Coordinating Council	L. G. Byrd	10,000[e]
	Task 41: AASHTO Guide for Recruitment and Retention of Transportation Professionals	Herb Golden	50,000
	Task 42: Development of National Truck Size and Weight Policy Recommendations	TRB	50,000
	Task 43: Revision of the AASHTO Policy on Geometric Design of Highways and Streets	—	—
	Task 44: Division 100 Revision of the AASHTO Guide Specifications for Highway Construction	Trauner Consultant	58,144*
	Task 45: Revision to the AASHTO Guide Specification for Seismic Design of Highway Bridges	SUNY	75,000
	Task 46: AASHTO Guidelines for Bridge Management Systems	Urban Institute	75,000
	Task 47: Support for the Joint Committee on Truck Size and Weight	—	30,000
	Task 48: Development of a System for the Uniform Location of Subject Matter Within Standard Specifications	—	73,570
	Task 49: Follow-up on U.S.A. Asphalt Study Tour of Europe	—	30,000
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*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
12/2/68	7/15/71	Completed—Rep. not publ.; sum. in NCHRP Res. Results Digest 55	(Task 4) 20-7
11/1/71	10/31/72	Completed—Published as NCHRP Report 150	(Task 5) 20-7
11/1/71	1/2/74	Completed—Published as NCHRP Report 157	(Task 6) 20-7
7/2/73	6/3/75	Completed—Published as NCHRP Report 203	(Task 7) 20-7
12/1/75	10/1/79	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	(Task 8) 20-7
12/1/75	8/31/76	Completed—Report not publ.; available only to sponsors	(Task 9) 20-7
1/3/77	12/15/78	Completed—Report not publ.; available only to sponsors	(Task 10) 20-7
1/1/77	10/31/78	Completed—Report not publ.; available only to sponsors	(Task 11) 20-7
6/1/77	6/30/78	Completed—Report publ. by AASHTO	(Task 12) 20-7
7/1/77	9/30/78	Completed—Published as NCHRP Report 214	(Task 13) 20-7
4/3/78	4/30/84	Completed—Report published by AASHTO	(Task 14) 20-7
8/29/78	12/31/81	Completed—Phase I rep. publ. as NCHRP Report 215; Phase II rep. not publ., but available for loan	(Task 15) 20-7
9/4/79	5/31/80	Completed—Report not publ.; distributed to sponsors	(Task 16) 20-7
7/1/79	12/31/83	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	(Task 17) 20-7
12/1/80	12/31/82	Completed—Report published by AASHTO	(Task 18) 20-7
5/19/81	2/15/82	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	(Task 19) 20-7
—	—	Completed—Results published in NCHRP Report 270	(Task 20) 20-7
7/1/82	12/31/83	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	(Task 21) 20-7
3/1/82	11/30/82	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	(Task 22) 20-7
7/26/82	4/17/84	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	(Task 23) 20-7
5/15/83	8/31/85	Completed—Report published by AASHTO	(Task 24) 20-7
3/1/84	5/7/84	Completed—Report available only to sponsors	(Task 25) 20-7
5/20/85	2/19/86	Completed—Report not publ.; for avail., see Summary of Progress Through 1988	(Task 26) 20-7
1/3/86	7/3/86	Completed—Report distributed to sponsors	(Task 27) 20-7
1/3/86	9/3/86	Completed—Rep. not publ., for avail., see Summary of Progress Through 1988	(Task 28) 20-7
—	—	Conducted under Project 1-23(2)	(Task 29) 20-7
12/12/86	9/30/87	Completed—Report being published by AASHTO	(Task 30) 20-7
10/15/86	10/14/87	Completed—Report distributed to sponsors	(Task 31) 20-7
11/1/86	3/31/88	Completed—Report distributed to sponsors	(Task 32) 20-7
9/29/86	7/31/87	Completed—Report distributed to sponsors	(Task 33) 20-7
9/6/88	6/30/91	Commentary published by AASHTO; report in review stage	(Task 34) 20-7
12/15/88	3/14/90	Completed—Report distributed to sponsors	(Task 35) 20-7
1/17/89	3/30/90	Completed—Report not publ.; agency rep. avail. on loan	(Task 36) 20-7
4/15/88	10/31/90	Completed—Report to be published by AASHTO	(Task 37) 20-7
1/2/89	10/31/90	Completed—Report published by AASHTO	(Task 38) 20-7
6/1/89	10/31/90	Completed—No report	(Task 39) 20-7
9/1/88	12/31/90	Completed—No report	(Task 40) 20-7
7/1/89	1/31/91	Completed—No report	(Task 41) 20-7
9/1/89	8/31/90	Completed—No report	(Task 42) 20-7
—	—	Cancelled	(Task 43) 20-7
2/12/90	9/14/90	Completed—Report distributed to sponsors	(Task 44) 20-7
7/1/91	7/31/92	Research in progress	(Task 45) 20-7
4/22/91	1/21/92	Research in progress	(Task 46) 20-7
—	—	In development stage	(Task 47) 20-7
7/22/91	8/23/92	Research in progress	(Task 48) 20-7
—	—	In development stage	(Task 49) 20-7
9/1/70	7/31/71	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-8
8/1/72	12/17/76	Completed—Rep. 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)

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY (*Continued*)		
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*
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 Transportation 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
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	49,786
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	—	300,000
20-25	Training Needs for Highway Construction Personnel	U of Maryland	73,728*
20-25(2)	Training for Highway Construction Personnel	SNI Training Services	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 Investment: Consideration of Rail and Highway Trade-offs	—	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	299,824
21-4	Sealing Geotechnical Exploratory Holes to Protect the Subsurface Environment	Strata Engrg Corp	300,000
21-5	Determination of Unknown Subsurface Bridge Foundations	—	350,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
9/1/72	5/31/74	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-11
9/1/75	11/30/76	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-11A
1/24/77	5/4/79	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988; sum. in NCHRP Res. Results Digest 114	20-11B 20-11B
4/1/77	3/31/78	Completed—Rep. 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—Rep. 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
9/1/87	12/31/89	Completed—Rep. not publ.; agency rep. avail. for loan	20-19(2)
10/1/84	9/30/86	Completed—See proj. writeup for report availability	20-20
3/15/85	5/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-20(2)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-20(3)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-20(5)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-20(6)
3/15/85	1/31/86	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	20-20(7)
4/12/85	2/26/86	Completed—Rep. 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	Report in revision stage	20-23
5/11/87	9/30/88	Completed—Report distributed to sponsors; sum. in NCHRP Research Results Digest 170	20-24
10/1/88	9/30/89	Completed—To be 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	Phases I and II completed; Phase III pending. Phases I and II reports in editorial and publication process	20-24(3)
7/1/90	4/30/91	Completed—Report in review stage	20-24(4)
8/1/91	1/31/93	Research in progress	20-24(5)
8/1/91	4/30/92	Research in progress	20-24(6)A
8/26/91	5/25/92	Research in progress	20-24(6)B
22 months		Contract pending	20-24(7)
6/15/89	12/31/90	Completed—Report not publ.; agency rep. avail. for loan	20-25
11/1/91	1/31/94	Research in progress	20-25(2)
6/1/89	9/30/90	Completed—Published as NCHRP Report 341	20-26
3/1/90	3/31/92	Research in progress	20-27
4/16/90	2/1/92	Research in progress	20-28
18 months		Contract pending	20-29
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 rep. avail. for loan	21-2(3)
12/4/89	3/3/92	Report in review stage	21-3
3/1/91	6/30/93	Research in progress	21-4
33 months		Contract pending	21-5

TABLE 4 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	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*
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 and 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	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	300,000
	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	—	300,000
25-5	Remote Sensing and Other Technologies for the Identification and Classification of Wetlands	—	300,000

* 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.
10/1/70	12/31/71	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988	22-1
3/1/74	5/30/75	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Dig. 81	22-1A
1/1/72	9/30/73	Completed—Phase I and Phase II (Task 1) reports not published; for avail., see Summary of Progress	22-2
10/1/73	3/31/75	Through 1988; summarized in NCHRP Res. Results Digests 84 and 102; Task 2 rep. publ. as NCHRP Rep. 153	
8/1/76	4/30/79	Completed—Agency reps. on Ph. I and Ph. 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—Rep. not publ.; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Dig. 76	22-3
7/1/74	12/31/74	Completed—Rep. not publ.; for avail., see Summary of Progress Through 1988; summarized in NCHRP Res. Results Dig. 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	Report in review stage	22-5A
6/1/85	11/30/88	Completed—Published as NCHRP Report 318	22-6
6/1/89	5/31/92	Report in revision stage	22-7
4/15/89	6/30/92	Research in progress	22-8
9/1/91	11/30/93	Research in progress	22-9
1/2/91	3/31/93	Research in progress	22-10
4/2/79	12/31/80	Completed—Report to be 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	12/14/92	Research in progress	24-5
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	4/15/92	Research in progress	25-3
27 months		In developmental stage	25-4
29 months		Contract pending	25-5

[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 5
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 4. Publication titles are given in Tables 6, 7, and 8.

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 Home-builders	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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
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.
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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
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 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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		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, Training Materials, and microcomputer applications	FHWA, National Hwy. Inst., State/Local Agencies, & Numerous Universities	As the basic training aid for short courses. More than 1,000 state and local officials have participated 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."

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
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.
		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.
12-28(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.
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, which includes a determination of the sets of road characteristics to which quality and quantity standards codes should be assigned.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		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.
	Synthesis 16	Conn. DOT	Reference source for design of CRC pavements.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	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$_{TM}$ (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.
	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."

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
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 6

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
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• 45	Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40
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• 48	Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20
• 49	National Survey of Transportation Attitudes and Be-

* Highway Research Board Special Report 80.

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TABLE 6 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
	havior—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
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• 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
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TABLE 6 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
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• 103	Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., $5.00
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• 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

TABLE 6 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
	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
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258	Control of Air Content in Concrete (Proj. 10-18), 84 p., $8.40

* Special publication.

TABLE 6 (*Continued*)

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260	Application of Statewide Freight Demand Forecasting Techniques (Proj. 20-17A), 210 p., $12.80
261	Cost-Effectiveness of Transportation Services for Handicapped Persons—Research Report (Proj. 8-27), 130 p., $9.60
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
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

TABLE 6 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
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
326	Development of a Roadway Design/Graphics Interface System (Proj. 15-10), 18 p., $8.00
327	Determining Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing (Proj. 10-27), 105 p., $11.00
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
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)), (In Preparation)
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)), (In preparation)

TABLE 6 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, 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 Trans-

TABLE 6 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PAGES, PRICE
	portation 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
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

TABLE 6 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PAGES, PRICE
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
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

TABLE 6 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PAGES, PRICE
166	Traffic Signal Control Equipment: State of the Art (Proj. 20-5, Topic 20-08), 43p., $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

TABLE 7
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

TABLE 7 (*Continued*)

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
134	20-6	Procedural Aspects of Inverse Condemnation—Title on Interest Acquired by Transportation and Other Public Agencies 13 p. $3.00
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
182[b]	20-5	Continuing Project to Synthesize Information on Highway Problems 8 p. $4.00

[a] See Table 4 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 8
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

TABLE 8 (*Continued*)

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
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

[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 FY '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 the North American Pavement Management Conference in 1985 and subsequent papers submitted for the Second North American Conference on Managing Pavements scheduled for November 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 is to analyze and evaluate the interaction between heavy vehicle characteristics and pavement performance for application in pavement management. Heavy vehicle (truck and bus) characteristics shall 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 to be considered shall 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 shall be analyzed and evaluated to determine their relationships and relative significance. Analytical and experimental procedures shall be 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 is to integrate existing mechanistic models of trucks and pavement structures into a cohesive vehicle/ roadway simulation system that will allow 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 can 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 can then be used as input to the pavement models for calculation of the road response and evaluation of pavement damage from the truck. The two models will then be combined into a system by which the results of the vehicle simulation are fed directly to the pavement response model for study of the interactive effects.

Flexible pavements are represented by means of influence functions derived from the multi-layer elastic model, VESYSDYN. Rigid pavement influence functions are obtained from a finite element model, ILLI-SLAB. The truck wheel dynamic loads are 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 is then evaluated to develop a statistical summary of damage from the passing truck.

Thirty-six truck configurations have been selected to represent the most common truck design variations currently in use, along with potential future variations. These configurations are being 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.

The preliminary draft final report has been submitted and is under review.

Project 1-26 FY '87 and FY '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: June 30, 1992
Funds: $499,942

During development of the revised *AASHTO Guide for 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, which has been completed, (1) selected from existing mechanistic technology those procedures suitable for accomplishment of the overall objective, (2) 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, (3) prepared a long-term plan for calibration and verification of the analysis procedure, and (4) 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.*

Phase II research is underway. Activities in this phase have 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" is cooperating 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.

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 will be announced via a Research Results Digest. 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: January 14, 1993
Funds: $425,000

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 is underway 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 and delivered to AASHTO for consideration. The first 3 tasks have been completed and Interim Report No. 1 has been submitted and approved. Work is underway on development of the laboratory test procedures.

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., pave-

ment 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:	June 30, 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 per-

formance. 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.

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: July 16, 1993
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., inven-

tory 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.

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 just underway.

Project 2-18 FY '91

Research Strategies for Improving Highway User Cost-Estimating Methodologies

Research Agency: Hickling Corporation
Principal Invest.: Jenifer Wishart
Effective Date: January 2, 1991
Completion Date: October 31, 1992
Funds: $150,000

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 is proceeding on schedule.

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 simula-

tion, 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 intersec-

tions, 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 over-used, 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. An evaluation of the system has been conducted by the FHWA. The final report will be available through the NCHRP.

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: June 30, 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 will: (1) evaluate the state of the art in operational analysis of ramp-freeway junctions, (2) develop and test a revised or new methodology for analyzing capacity and LOS at these junctions, and (3) verify the proposed method with an extensive field data collection effort.

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

To accomplish this objective, the project will be performed in two phases:

Phase I

Task 1. Evaluate the adequacy of the procedures in Chapter 5 of the 1985 HCM. Survey users to determine their experience in applying the procedures to identify deficiencies and needed improvements. Evaluate new information and procedures that should be considered. Appraise the ability of current procedures to predict traffic flow phenomena and identify any deficiencies. This task will not require major field data collection.

Task 2. Propose an improved model or models, where needed to overcome the deficiencies identified in Task 1. The model(s) shall relate capacity and LOS to an appropriate set of site-specific characteristics. The research shall consider the characteristics used in the current methodology and, as a minimum, consider the following additional characteristics: (a) angle of convergence/divergence; (b) length of acceleration/deceleration lane and recovery zone; (c) tapered vs. parallel design; (d) ramp roadway geometrics (including curvature, grades, sight distance, operating speed and width); (e) ramp vehicle arrival patterns (specifically random arrivals, platoon arrivals, and ramp metered arrivals); (f) ratio of ramp to main line lane volumes; and (g) number of lanes and volume distribution on ramp and main line.

In addition, other characteristics identified as having a significant impact on capacity and LOS should be considered. The treatment of ramp configurations shown in Figure 5-1 and Table 5-2 of the HCM shall be extended to include those additional configurations identified in Task 1. The recommended model(s) shall reflect changes in driver behavior and vehicle fleet and performance. Those characteristics and relationships that can be demonstrated to have no significant influence on capacity or level of service may be eliminated from future consideration.

The proposed model(s) shall be based on a systematic approach which represents a rational and logical application of the principles of traffic flow. Modification or expansion of the current LOS criteria may be considered, if warranted.

Task 3. Prepare a field data collection and analysis plan to quantify the traffic flow relationships among the parameters identified in Task 2. The interval used for analysis shall not exceed 15 min. Investigate the existence of current usable field data before preparing the plan. To the extent possible, sites for data collection shall represent a variety of nationwide geographical locations, traffic demands, geometrics, and other key conditions. 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.

An interim report was submitted for review by the NCHRP panel before proceeding with Task 4. The interim report will discuss the proposed model(s) and support any substantial changes from the existing methodology. It will also describe the plan for data collection and analysis in detail.

Task 4. Select a minimum of five representative sites for a pilot study and implement the data collection and analysis procedures developed in Task 3. Based on the data collected, evaluate the model(s) proposed in Task 2.

Task 5. Prepare a Phase I report including (1) a preliminary evaluation of the proposed model(s), (2) the proposed data collection and analysis plan, and (3) a revised, detailed budget for Phase II. The data collection plan should include site selection for approximately 50 sites including those in the pilot study. The researchers will 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.

Phase II

Task 6. Collect field data according to the approved plan. Data will be collected under good weather conditions in daylight.

Task 7. Reduce and analyze the data collected under Task 6 to calibrate the model(s). Select the appropriate model(s) for inclusion in the final report.

Task 8. Prepare a final report describing the form and content of the capacity and level-of-service analysis procedures. This report will include any procedural revisions necessitated by the data collection and analysis effort and the final values adopted for the relationships used in the analysis procedures. The level of precision and sensitivity of the procedures will be estimated. This report will be subject to review and acceptance by the NCHRP panel and TRB's Highway Capacity Committee prior to starting Tasks 9 and 10.

Task 9. Prepare a new version of HCM Chapter 5, "Ramps and Ramp Junctions," containing the new analysis procedures. This material will follow the style of the 1985 HCM and will be suitable for use without any changes, other than typesetting. Figures, tables, and photographs will be in final camera-ready form.

Task 10. Implement the procedures of this project in the HCS module for Ramp and Ramp Junctions which is currently distributed and maintained by the McTrans Center. This task will require modifying the existing module or preparing a new module. The modified or new module will use the language, software standards, and "look and feel" of the HCS. Fully documented source code and modified user documentation will be provided. The new version of the HCM Chapter 5 produced in Task 9, and the new version of the HCS produced in Task 10, will be reviewed and approved by the NCHRP project panel.

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

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), intra-site 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:	Sep. 1, 1988	Dec. 15, 1990
Completion Date:	Mar. 15, 1990	Jun. 30, 1992
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 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 this research are 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.

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

Task 1—A thorough review of existing CIC strategies will be conducted. Based on this review, a CIC strategy and potential test site(s) suitable for a comprehensive field evaluation will be recommended.

Task 2—A field evaluation plan to determine the effectiveness of the CIC strategy selected will be developed. This evaluation will be based on a variety of geometric configurations, intersection spacings, traffic signal timing and phasing, demand/capacity levels, and operational conditions (e.g., effects on downstream intersections).

Task 3—Following a decision to proceed, the field evaluation for the strategy selected will be performed. A report documenting the results will be submitted.

Task 4—Detailed recommendations for potential improvements to the CIC strategy evaluated will be developed.

Task 5—Comprehensive guidelines for the use of the CIC strategy evaluated in Task 3 will be developed. These guidelines will address issues relative to CIC applicability, constraints and limitations, selection of parameters and coefficients used in the smoothing algorithms and demand equations, and traffic conditions under which CIC should be activated by the system. A user manual that documents the guidelines in a format and style suitable for use by operators of computerized signal systems will be prepared.

Task 6—A final report documenting all methodology and results will be prepared.

All research has been completed, and the final report has been delivered to NCHRP. The CIC algorithm, in general, was found to perform no better than the fixed-time signal timing plan alternative. The researchers concluded that CIC algorithm is 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 will not be 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 will be initiating a study of a new traffic signal control approach known as "Optimized Policies for Adaptive Control Strategy," or OPA strategy.

The objectives of "Traffic Adaptive Control (Phase II)—OPAC Control Strategies" will be: (1) enhance the isolated intersection control version of OPAC which, following successful testing, can 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.

To accomplish the objectives the following tasks are being conducted: (1) Determine what software enhancements are needed to make OPAC fully operational as an isolated intersection control logic and as part of a computer-controlled signal system. As a minimum, the enhancements to the OPAC software should take into account control for left-turn movements, pedestrians, and the impact on downstream link performance. (2) Using the TRAF-NETSIM model supplied by FHWA, conduct simulated tests to verify the proper operation of the software developed in Task 1. Determine the sensitivity of the parameters affecting the OPAC strategy including, but not limited to, detector location, interval length, head and tail lengths, tail composition, traffic speeds, and the effects of sinks/sources within the links. Determine the threshold values of congestion at which OPAC effectiveness is degraded relative to the effectiveness of conventionally employed control strategies. (3) Prepare an interim report documenting the results of Tasks 1 and 2 and providing guidelines and recommendations for the application of OPAC to isolated intersections. The interim report will be reviewed by the NCHRP panel, and work on the remaining Tasks will be subject to NCHRP approval. (4) Contingent on the successful completion of Tasks 1-3, recommend for NCHRP approval four suitable field-test locations where the responsible operating agency(s) will agree to contribute the operating surveillance system needed to conduct OPAC field tests. For the four locations selected, OPAC shall be implemented as an isolated intersection control system at two locations and as part of a computer-controlled signal system at the remaining two locations. (5) Following NCHRP approval of the field test locations, develop the necessary software to integrate the OPAC control logic with the selected computer controlled signal systems. (6) Conduct the field evaluations at the selected locations to include before-and-after studies. Prepare an interim report documenting the results of the field tests. (7) Produce the necessary documentation required to finalize the development of OPAC into an implementable product. As a minimum, this will include: HIPO charts, pseudo code, and documented and updated source code. Develop procedures for the field calibration of OPAC parameters by practitioners. (8) Prepare and submit a final report.

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: February 1, 1991
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. Signal-timing strategies based on progression are not optimal in these situations. Latent queues that were not able to clear during previous cycles may cause the progression scheme to break down. In fact, progression schemes that allow the arrival of platoons at the rear of a latent queue may worsen the problem by effectively lengthening the queue. These queues may grow to sufficient length to adversely affect upstream intersection operations. These conditions are true during peak period (recurring) congestion and also in nonrecurring congestion caused by special events or incidents.

The objectives of this research are to: (1) develop a user manual containing 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.

To accomplish the first objective, the following tasks have been conducted:

Task 1—A number of scenarios that describe saturated conditions for a wide range of network geometry, traffic demand, and operating conditions will be defined. Consideration will be given to approach length, number of approach lanes and their usage, pedestrian crossing requirements and interference with turning traffic, actuated and fixed-time control, upstream turning movements, and downstream bottlenecks (e.g., bridge, tunnel, lane reductions, etc.).

Task 2—A set of signal-timing strategies that can be used to minimize the impact of saturated traffic flow con-

ditions will be prepared. Consideration will be given to strategies that include simultaneous and reverse progression schemes and metering of upstream or side-street traffic flow.

Task 3—For each scenario defined in Task 1, alternative signal-timing strategies from the set of strategies developed in Task 2 for evaluation will be selected. Appropriate signal-timing parameters (e.g., cycle length, phase sequencing and timing, and offsets) for each alternative to be evaluated will be developed. An interim report documenting the results of Tasks 1 through 3 will be submitted before proceeding further.

Task 4—Using the NETSIM model, the effectiveness of the alternative signal-timing strategies developed in Task 3 for each scenario will be evaluated. From the analysis of these results, procedures and guidelines that can be used by practicing engineers to select the appropriate timing strategy for a given set of geometric, signal-timing, and traffic demand parameters will be developed.

Task 5—A user manual that describes the timing strategies developed in Task 2 and contains the procedures and guidelines developed in Task 4 will be developed. Full documentation of the simulations and analysis conducted in Task 4 will be included as an appendix in the manual.

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

Task 6—Procedures that can be used in computerized signal systems for real-time response to both recurring and nonrecurring congestion will be developed. These procedures will include algorithms and detector placement guidelines for determining the onset and termination of saturation. They will also include signal-timing strategies that can respond in real-time to the detection of saturation. (The signal-timing strategies to be investigated will not be limited to those studied in the previous tasks). Cost and time estimates to (1) install the detectors; (2) develop, test, and install the necessary software; and (3) conduct before-after field evaluations at several test sites will be prepared. These estimates will provide the basis for a subsequent research project.

Task 7—Prepare final report.

The research has fallen badly behind. In the early stages of the research there were problems associated with obtaining the latest version of the FHWA NETSIM traffic simulation model. After the NETSIM model was obtained and thoroughly tested, a new traffic control algorithm was formulated, presented at a technical conference and then provided to the NCHRP project panel for their review. The panel met with the researchers and provided feedback on the new algorithm. The panel's initial response to the new algorithm was favorable. Following the panel meeting the researchers then began a series of tests of the algorithm using NETSIM. The initial testing resulted in disappointing, counter-intuitive performance. As a consequence the researchers undertook restructuring of the algorithm to be followed by additional simulation testing.

At the end of the reporting period work was completed on all tasks and a draft of the final report was in preparation. The research agency estimates that the final report will be delivered about January 1992.

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 ca-

pacity 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 will be 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 is completed, and the preliminary draft final report is under review.

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
Completion Date:	April 30, 1991
Funds:	$124,789

Streets and highways constitute a major public investment, and it is essential to operate them safely and efficiently. Inadequate access management is an important factor behind the operational deterioration of many of our streets and highways. There is a need to identify better methods for applying access management practices to different classes of highways within the vicinity of activity centers, and for implementing such practices on highways experiencing access management problems.

The objective of this research is to develop policies and guidelines to preserve and improve the capacity and safety of the overall highway system within the vicinity of activity centers through better management of access control. These guidelines would apply to (1) modification of access control on streets and highways where activity-center development has already occurred, (2) planning access control in newly developed areas or for new highways being constructed in existing developed areas, and (3) management of access control within activity centers.

To meet this objective, the following tasks shall be accomplished:

Task 1. Conduct a detailed review of literature, a survey of State and local governments, and a survey of activity center developers and managers. The purpose of these activities in two-fold: (1) to identify problems currently being experienced on highways and streets in the vicinity of activity centers and (2) to identify current successful practices for management of access to activity centers along major streets and highways. As a minimum the following information shall be collected:

- What access management policy(s) are in place?
- Are these policies backed by legislation?
- Do the policies or legislation authorize the retrofit of access management on existing streets and highways within the vicinity of activity centers?
- Do existing policies include access design standards?
- Do access design standards vary by highway functional class?
- How is enforcement of the policy handled?
- Are standards and policy administered by State, regional, or local government? How is coordination

handled? How are conflicts between standards of different jurisdictions handled?
- What is the typical design year used for analysis of access adequacy for activity centers?
- What are the typical problems with current policies, guidelines, and standards? For example, what existing components should be eliminated? What existing components should be changed? What components should be added?
- If there were no constraints (political, funding, or personnel), what would the ideal access management policy for activity centers include?

Task 2. Prepare a report summarizing the material gathered during Task 1. This report shall be appropriate for publication as a synthesis and evaluation of current practices in access management for activity centers.

Task 3. Prepare a draft report recommending policies and guidelines that can be used for managing access on streets and highways in the vicinity of activity centers. This draft report shall be circulated for review and comment to a representative sample of the Task 1 survey respondents.

Task 4. At a meeting of the NCHRP project panel, present a summary of the responses to the Task 3 draft report and make recommendations regarding whether or not additional research is required.

Task 5. Prepare a final report on Recommended Access Management Policy and Guidelines for Activity Centers.

All research is completed and the panel has favorably reviewed the final report. The final report will be published in early 1992.

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 Cunagain
Effective Date:	March 1, 1988
Completion Date:	October 30, 1991
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.

Tasks 1 through 4D have been completed. A draft final report is under review by the panel.

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 agenices 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 will be published in early 1992.

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: April 15, 1992
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.

Delays in obtaining accident data have prevented the completion of the planned analyses. Most of the accident data has been obtained and efforts are underway to complete the analyses.

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, road-

way 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.

The researchers have prepared several position papers on the Task 1 findings on the subjects of Driver-Vehicle-Roadway Relationships, Accident Data and Related Information and Alternative SSD Models.

Project 3-43 FY '91

Use of Shoulders and Narrow Lanes to Increase Freeway Capacity

Research Agency: J.H.K. & 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. As this approach is considered more widely, there is a need to fully understand the trade-offs among facility design, traffic performance, safety, enforcement, system operations, and maintenance impacts. Further, there is a need to provide guidance to agencies responsible for evaluation and selection of an optimal combination of lane and shoulder widths.

The focus of this project is on strategies for adding capacity to existing freeways, within the existing right-of-way, through the use of shoulders, both as a stand-alone strategy or in conjunction with reduced lane widths. The objectives of this project are to formulate a methodology to evaluate potential applications of these strategies and to develop recommendations and design guidelines for their use.

This project consists of two phases. The following tasks comprise Phase I:

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 as it relates to facility design, traffic performance, safety, enforcement, system operations, and maintenance issues; 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. The research plan may, in addition to others, consider techniques such as: (1) field studies, (2) case studies, (3) traditional accident data collection and analysis, and (4) synthesis of previous research and experience.

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-of-effectiveness to be used in evaluating alternatives; and (4) presents a detailed research plan and revised budget required to complete Phase II.

The following Tasks comprise Phase II:

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 non-freeway 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.

Research on Tasks 1 through 3 has been completed and the panel is reviewing the Interim Report.

Project 3-44 FY 92

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

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (30 months)
Completion Date:
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.

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 final report was revised after review by the panel. A Research Results Digest summarizing the research findings will be published in early 1992.

Project 4-18 FY 92

Design and Evaluation of Large Stone Mixtures

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (30 months)
Completion Date:
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 will consider the effects of aggregate shape, grading, and binder characteristics on LSM performance. The scope of this research will include LSM having a maximum aggregate size between 1 in. and 2½ in., inclusive.

Accomplishment of these objectives will require, as a minimum, the following tasks:

Task 1 State of the Art. Review and analyze currently used laboratory design procedures, specifications, and construction practices for LSM,

Task 2 Effectiveness of LSM. Collect and analyze LSM field-performance data, including traffic information and environmental conditions. These data may be obtained from reports, interviews, and site visits, and may be combined with results of laboratory tests on field samples, where warranted, to assess the effectiveness of LSM in minimizing plastic deformation.

Task 3 Interim Report. Submit an interim report within 9 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 Tasks 4 and 5. NCHRP approval of the interim report and the proposed plan will be required before commencing the remaining tasks.

Task 4 Mix Design Procedure. Develop a mixture-design procedure to determine the optimum proportions of the aggregate and binder to be used in LSM. The procedure should be applicable to mixtures with various aggregate gradings; however, it may be necessary to develop modifications for open-graded mixtures. The procedure must include specimen fabrication, test methods, and mixture design criteria. Sample sizes and the number of replicates shall be included.

Task 5 Mixture Analysis. Develop detailed laboratory test procedures to evaluate the resistance of large stone mixtures to plastic deformation and moisture damage. It is anticipated that existing methods and equipment can be used, with some modifications, to accomplish this task. The researchers are expected to determine how changes in maximum particle size, shape, and grading affect the resistance of LSM to plastic deformation.

Task 6 Constructibility. Based on availiable 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.

Task 7 Final Report. Prepare a final report documenting the research effort and the research findings.

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: $200,000

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. A decision on publication of the final report is pending. Loan copies of the final report are available from the NCHRP.

Project 5-12 FY '92

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

Research Agency: In developmental stage
Principal Invest.:
Effective Date: (30 months)
Completion Date:
Funds: $250,000

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

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: April 30, 1992
Funds: $200,000

The objective of this study is to develop a comprehensive, user-friendly, portable microcomputer program ca-

pable 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.

Tasks 1 through 5 have been completed. Work is nearly complete on Tasks 6, 7, and 8, but software problems have delayed the beginning of the testing phase. It is expected that the testing will be initiated in January 1992.

Project 7-13 FY '92

Quantifying Congestion

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	(24 months)
Completion Date:	
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.

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 Associates, Inc.
Principal Invest.:	John R. Hamburg
Effective Date:	February 15, 1991
Completion Date:	August 15, 1992
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. This uncertainty is underscored by recent observations that many of the underlying travel relationships that formed the basis of *NCHRP Report 187* appear to have shifted. These include changes in travel patterns, trip generation rates, trip chaining and activity patterns, trip length, urban forms (free standing, exurban/suburban), and multiple use sites. The nature of transportation planning has also been changing. Many agencies are focusing on site-impact mitigation which reinforces the need for systems-level planning, to coordinate transportation improvements, even in small communities. 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.

In summary, there is a critical need to update transportation planning parameters. Many urban jurisdictions are using default data and relationships in applying microcomputer travel-demand forecasting models. In smaller urban areas, the *NCHRP Report 187* transferable parameters are often the major source of data for transportation studies. The primary focus of this research will be on the needs of the small-to-medium-sized (25,000 to 500,000 population) urban areas, both free-standing and within the influence of larger metropolitan areas.

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.

Accomplishment of the objectives will require, as a minimum, the following tasks:

Phase I:

Task 1. Review and summarize trends in travel behavior, urban structure, related planning issues, and the state of the practice in planning procedures.

Task 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.

Task 3. Conduct a user survey to determine deficiencies, strengths, applicability, and suggested improvements to *NCHRP Report 187.*

Task 4. Identify which parameters and techniques are in critical need of updating. Examples of parameters that should be examined include trip generation rates, peak-hour factors, pass-by factors, time-of-day factors, auto occupancy rates, linked trip characteristics, external travel, trip purpose percentages, and others identified in the trend analysis or user survey.

Task 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. The revised budget shall include two alternative research plans: (1) activities to be accomplished within a total contract expenditure of $200,000, and (2) activities to be accomplished if additional funds become available permitting a total contract expenditure of $300,000.

NOTE: No more than $40,000 shall be spent in the performance of Tasks 1 through 5. Authorization to proceed with Phase II will depend on satisfactory completion of Phase I and subsequent approval by the NCHRP.

Phase II:

Task 6. Identify and assemble travel survey data collected by state highway agencies, metropolitan and local planning agencies, and other appropriate sources, including Census journey-to-work information and the National Personal Transportation Study. Target sources and data will include existing home interviews, external travel surveys, roadside surveys, mode choice parameters, travel impedance, auto occupancy, and time-of-day travel characteristics. The factors affecting transferability and level of accuracy of compiled data shall be assessed. The scope

of this task is not intended to include collection of primary data or development of software.

Task 7. Organize data, develop the appropriate parameters, and describe appropriate techniques. Data categorization must address, as a minimum, such issues as: parameter transferability between city sizes, urban forms, and socio-economic characteristics.

Task 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.

Tasks 1 and 2 have been completed and the Task 3 survey has been mailed.

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:	$660,017

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.

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 and FY '83

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:	July 1, 1989
Funds:	$497,335

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 has recommended that field observations be continued on these test sections until original objectives are satisfied. Consideration is being given as to how this may best be accomplished.

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 provide a critical state-of-the-art review of design and construction procedures for pot bearings.

The Phase III research on unconfined elastomeric bearings included (1) an experimental investigation of the low temperature behavior of bearing elastomers; (2) development of guidelines for recommended manufacturing procedures and tolerances; (3) development of recommended bearing prequalification procedures and tests; and (4) revi-

sion of the specification developed in Phase II on the basis of the Phase III experimental work.

Phase III research has been completed. The pot bearing research has been summarized in the NCHRP Research Results Digest 171, "Pot Bearings and PTFE Surfaces." The report on unconfined elastomeric bearings will be published in early 1990, and the recommendations from that report are expected to be considered by the AASHTO Bridge Committee in mid-1990.

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:	February 28, 1992
Funds:	$250,000

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.

The recommended specifications that will be submitted at the end of the project will include provisions for the existing *Standard Specifications for Highway Bridges* as well as provisions for the LRFD-based specification presently under development in NCHRP Project 12-33.

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 transportation 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: January 30, 1992
Funds: $490,000

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 has been completed, and the final report and recommended specification are being reviewed by the NCHRP panel.

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.:	Gareth John and F. M. Burdekin
Effective Date:	July 1, 1987
Completion Date:	August 31, 1990
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. Final disposition of all project equipment and a decision on the publication of the final research report are pending. In the meantime, loan copies of the final report are available on request.

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: March 31, 1991
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.

All experimental research and data analysis are now complete.

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, to be jointly funded by FHWA and NCHRP, will be initiated early in 1991. Funding of $160,000 will be provided for 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 on Tasks 1 through 3 has been completed, and the panel has reviewed the Task 2 field guidelines and the Task 3 training materials.

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

Many existing bridges cannot accommodate the increasing traffic volumes and loads that are required for new bridge designs; therefore, highway agencies are spending large sums of money in rehabilitating, widening, and repairing these structures. Designs in some cases rely on the capacity of welded and mechanical reinforcing steel splices to transfer loads from the new steel reinforcement to the existing reinforcement. It is often necessary to place these splices in regions of high stress range. The behavior under cyclic stress conditions of many currently used splice configurations has never been adequately determined.

AASHTO specifications are available for consideration of fatigue strength in the design of welded details in structural steel members. Similar guidelines are not available for welded details in reinforcing steel. The American Welding Society's AWS-D1.4 provides standards for fabricating welded reinforcing splices, but provides no information on their fatigue performance. Additionally, the AASHTO Standard Specification for Highway Bridges limits the stress range for reinforcing steel, but provides no guidance on the allowable stresses in welded or mechanical splices.

Some fatigue testing of reinforcing steel splices has been performed. Many of these tests were performed for the nuclear power industry and concentrated on low cycle/high stress range tests on large diameter bars. The results from these tests may be applicable to the development of guidelines for the design of bridge components subject to seismic loadings. It is uncertain, however, whether data exist for the fatigue behavior of reinforcing steel splices under high cycle/low stress range effects.

Research is needed to assess the fatigue behavior of welded and mechanical reinforcing steel splices. On the basis of this assessment, guidelines will be formulated for use by the designer involved in the rehabilitation and design of highway bridges. Better understanding of the fatigue behavior of welded and mechanical splices in reinforcing steel will provide for more cost-effective design, preventive maintenance, and assurance of public safety.

The objective of this research is to evaluate the fatigue behavior of, and develop practical fatigue design guidelines for, welded and mechanical splices for reinforcing steel in bridges.

The research will include 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, consultants, and owners of concrete structures.

Task 2—Summarize and evaluate the information generated in Task 1 on the design, application, and fatigue behavior of welded and mechanical splices in reinforcing steel.

Task 3—Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 8 months after initiation of the study. The interim report shall con-

tain a detailed research plan for Task 4 and a framework for the design guidelines to be developed under Task 6.

Task 4—Conduct laboratory tests in accordance with the detailed research plan presented in the interim report. The testing shall consist of constant amplitude fatigue tests in stress ranges realistic for highway structures.

Task 5—Analyze and evaluate all relevant fatigue test results from Tasks 2 and 4, and summarize the findings.

Task 6—Develop recommended design guidelines in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended guidelines shall be accompanied by a detailed commentary and examples of specific bridge applications intended to facilitate understanding and use of the guidelines.

Task 7—Prepare and submit a final report containing the research findings, proposed guidelines, and recommendations for further research.

Research on the project has been completed. The final report has been submitted for panel review and will provide recommended specification provisions for incorporation into the AASHTO *Standard Specifications for Highway Bridges.*

Project 10-36 FY '88

Evaluation of Weldments Incorporating Backing Materials

Research Agency: Fleet Technology Limited
Principal Invest.: Lalit Malik
Effective Date: May 2, 1988
Completion Date: March 31, 1992
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.

It is expected that the final report will include recommendations on the use of non-fused materials as well as fused backing materials with applied cyclic stresses transverse to the axis of the weldment.

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. Some of the factors to be evaluated may include, but are not limited to:

- Coating condition (chemical analysis, adhesion, thickness, cure, ultraviolet light degradation, "holidays," damage, softening, hardening, moisture content).
- Reinforcement surface condition (cleanliness, anchor pattern).
- Concrete condition (concrete analysis, chloride and moisture contents).
- Environmental factors (temperature, time of wetness).
- Structure condition (delaminations, cover).

Develop an evaluation methodology using the techniques identified (or developed) and perform a preliminary examination on one existing concrete bridge and on reinforcing steel for a bridge prior to placing concrete to demonstrate the viability of the techniques.

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. In selecting structures, the contractor shall consider at least the following factors:

For structures in service

- Damaged structures in the Florida Keys
- Undamaged structures in severe environments
- Other environments (cold marine, deicing chemicals)
- Structural elements (substructures, decks, barrier walls)
- Bar parameters (straight, bent, size)

For structures prior to concrete placement

- Environmental conditions (ultraviolet light, contaminants, temperature)
- Storage of bars (methods, duration)
- Local conditions (practices, specifications)

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. Two months are expected to be required for review by the NCHRP.

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 and 2 are underway. As part of the information gathering, the researchers have visited the bridges in the Florida keys and are examining some interesting European practices and developments as well as North America's. Documentation of Task 1 is expected soon with further Task 2 experimentation required.

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

Fatigue cracks have developed at the ends of coverplates in beams that are only infrequently subjected to stress ranges exceeding the fatigue limit of AASHTO's Category E'. For example, in one particular structure, small cracks have been detected in several beams where only 0.1 percent of the measured stress cycles exceeded the estimated fatigue limit. This observed field behavior suggests that more severe fatigue problems could result if bridges are subjected to heavier loads in the future, and the consequences of occasional overloads from permits and other sources may be more critical than previously assumed.

The objective of this study is to extend the findings of Project 12-15(4) 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. Testing will be carried out on eight full-scale welded girders.

The currently available test data in this region of behavior are very sparse and do not provide an adequate basis on which to assess this problem. The consequences of triggering fatigue crack growth in existing bridges as a result of increased loads could have a major impact on the life expectancy and safety of bridges on high volume arteries where large numbers of random variable-stress cycles are expected.

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."

Research on the project has been completed, and the final report has been submitted.

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.: Abba G. Lichtenstein
Effective Date: January 3, 1989
Completion Date: January 3, 1992
Funds: $228,800

The AASHTO *Manual for Maintenance Inspection of Bridges* is intended as a guide to provide uniformity in the inspection procedures and evaluation techniques for all bridges on public roads. The Manual was initially adopted

by AASHTO in 1970, and since that time only minor changes and additions have been made. Many subsequent advances in analytical and practical techniques are being used in bridge design, construction, and evaluation, but have not been reflected in the Manual.

Research is needed to update the existing Manual. A thorough review and revision of the inspection and evaluation criteria, on the basis of current technology and recently completed and on-going research, will result in better assessment of the condition and load capacity of existing bridges.

The objective of this manual is to develop a revised *Manual for Maintenance Inspection of Bridges* that can be recommended to AASHTO for consideration for adoption.

In developing the revised Manual, consideration shall be given to current practice, recently completed and on-going research, and appropriate AASHTO committee and FHWA activities to provide: (1) guidance for inspection, evaluation, and load capacity rating of existing bridges; (2) a recommended method for load capacity rating along with acceptable alternate methods; (3) appropriate consideration of inspection requirements and preparation of inspection reports; (4) a methodology for assessing the safe load capacity from load tests; and (5) consideration of fatigue and other serviceability requirements. The revised manual shall also include consideration of factors such as scour, redundancy, and detail criticality and evaluation procedures that are applicable to bridge management systems.

The revised Manual shall be prepared in a flexible format that allows for future revisions, and a commentary shall also be provided.

The project will include the following tasks:

Task 1. Review relevant literature and current domestic and foreign procedures and specifications for inspection, evaluation, and load capacity rating of existing bridges and other structures.

Task 2. After evaluating the information developed in Task 1, prepare a comprehensive list of, and rationale for, recommended revisions to the existing Manual.

Task 3. Prepare a detailed outline for a revised Manual. As a minimum, the outline shall include chapter and topical headings along with a description of the intent of each topic.

Task 4. Present the findings of Tasks 1, 2, and 3 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 5.

Task 5. Prepare a revised Manual and commentary in a format suitable for consideration by the AASHTO Highway Subcommittee on Bridges and Structures. Both shall be prepared in a format that can be easily updated in the future.

Task 6. Prepare a final report.

Research on the project has been completed, and a draft of the Manual will be submitted for balloting on the recommended specifications by AASHTO.

Project 12-26 FY '85 and FY '89

Distribution of Wheel Loads on Highway Bridges

Research Agency:	Imbsen & Associates, Inc.	
Principal Invest.:	Roy A. Imbsen	
Effective Date:	April 15, 1985	August 22, 1988
Completion Date:	December 15, 1987	October 31, 1990
Funds:	$300,000	$200,000

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 Phase I final report was not published, but was distributed to NCHRP sponsors in mid-1988. Copies are available on loan or microfiche (see final page of this document for ordering information).

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.

Research on Phase II has been completed, and copies of the final report were distributed to the program sponsors. The specification recommendations will be considered for adoption by AASHTO.

A third phase of work will be initiated in 1992. This phase will result in the development of a PC-based wheel load distribution computer program based on grid analysis methods. The software should be available in 1993.

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: Contract Pending
Principal Invest.:
Effective Date: (18 months)
Completion Date:
Funds: $350,000

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 necessary 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.

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.: 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 has been submitted and is in the revision stage.

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.

Research has been completed and the final report will be published in early 1992. 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. In addition, the report provides recommendations on retrofit procedures that one may use to take advantage of inelastic redistribution and the rating 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:	June 16, 1993
Funds:	$200,000

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. Submit the draft procedures for NCHRP panel review and approval.

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. This task will include the following steps: (a) prepare an outline of the manual and submit it for NCHRP panel review and approval; (b) prepare and submit a draft manual for panel review and approval; and (c) prepare a revised manual after receiving NCHRP approval of the draft manual. The revised manual must be submitted within 16 months of project initiation.

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. Prepare a draft course outline for panel review and approval. Submit a final course outline for NCHRP review and approval prior to initiation of the remaining project tasks.

Task 4. Prepare course materials. This will include preparation of an Instructor's Manual, a Student's Manual, and necessary audio and visual aids. Submit the complete course package to the NCHRP for panel review and approval.

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.

Through December 31, 1991, research on the project is proceeding on schedule. The Task 1 report was submitted by the agency and reviewed by the NCHRP project panel. Minor changes were recommended for the proposed rating procedures, which will be incorporated in the manual under development in Task 2.

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 recently completed 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.

The objective of this project is to establish the variability of CVN impact notch toughness within plates of A572 Grade 50 and A588 steels for plate thicknesses up to 4 inches meeting AASHTO Zone 3 fracture notch toughness requirements. The research will include the following tasks:

Task 1—Review relevant research findings and performance data in the literature on notch toughness variability within steel plates. In particular, meet with representatives of AISI to review the information developed by AISI on such variability of steel plates meeting Zones 1 and 2 notch toughness requirements.

Task 2—Review the various methods available for analyzing variability in notch toughness data within steel plates.

Task 3—Based on the results of Tasks 1 and 2, select a method of analysis of test results and develop a system for reporting test results that will be useful to bridge engineers. Present the findings of Tasks 1, 2, and 3 in an interim report to be submitted not later than 9 months after initiation of the study.

Task 4—Concurrently with Task 1, obtain plates of A572 Grade 50 and A588 to meet AASHTO Zone 3 toughness requirements, as specified in the 1978 AASHTO *Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members.*

Task 5—Develop a specific test matrix to study the variability of CVN impact notch toughness within each plate. As a minimum, nine locations per plate shall be studied.

Task 6—Perform chemical analyses and tensile tests for each plate. Three longitudinal CVN specimens shall be machined from the plate blank at each location and impact tested at +10°F, i.e., the AASHTO Zone 3 test temperature. In addition, full transition curves shall be obtained for longitudinal CVN specimens at 3 locations.

Task 7—Analyze the test results using the methodology developed in Task 3. Only values which are the average of three specimens shall be analyzed. Variability within each plate shall be determined and compared with the average results from the mill report and compared with the 1978 AASHTO Guide Specification requirements.

Task 8—Should there be any unusually low notch toughness values at any location, an investigation shall be made to establish the reason.

Task 9—Prepare a final report documenting the findings of the research including recommendations for needed specification revisions.

Research on the project has been completed. The final report was submitted and was reviewed by the project panel and representatives of the steel industry. A revised report was subsequently submitted and is being reviewed for technical acceptability.

Project 12-33 FY '88, FY '89, FY '90, and FY '91

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:	March 31, 1992
Funds:	$797,147

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 has been completed. 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 consider-

ation 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.

It is estimated that a completely new LRFD-based bridge specification will be developed in 45 months at a cost of approximately $1.75 million.

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.

The second draft of the new specification was completed and has been distributed to AASHTO. Fourteen states performed more than 40 superstructure designs with the draft. These trial designs were presented and discussed at a special meeting of the AASHTO Highway Subcommittee on Bridges and Structures in September 1991.

Based on the results of this meeting, it was clear that the specifications and commentary are "user friendly" and more complete than the existing AASHTO bridge design specifications. However, there were areas identified which will need correction during work on the final draft. That work is now underway and should result in a final NCHRP draft for distribution to and consideration by AASHTO.

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 will be 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 will be employed during the course of the project for various tasks and responsibilities.

The agency employed on Project 12-33B will act under the direction of the Principal Investigator on Project 12-33, Dr. John Kulicki. Imbsen & Associates, Inc., will be 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 will be employed during the course of the project for various tasks and responsibilities.

The agency employed on Project 12-33C will act under the direction of the Principal Investigator on Project 12-33, Dr. John Kulicki. D'Appolonia will be 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: July 7, 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 se-

verely 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.

Through December 31, 1991, research on the project has progressed on schedule. The first 3 tasks have been completed and the interim report was submitted for panel review at the end of 1991. Work will start on the remaining tasks in early 1992.

Project 12-37 FY '92

Transverse Cracking in Newly Constructed Bridge Decks

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (36 months)
Completion Date:
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.

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, Inc.
Principal Invest.: Dr. T. S. Shuler
Effective Date: January 1, 1991
Completion Date: December 31, 1992
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 has been 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 has been submitted and is under review. 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 has been received 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. Contacts with state highway personnel indicate there is considerable reluctance to permit use of chip seal coats on major highways because of possible legal consequences from windshield damage. On the other hand, such treatments are used extensively in countries other than the United States. Three field test projects have been conducted in: Oklahoma, California, and Virginia. Data from these field tests are being analyzed. Other field sites are under consideration.

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 16, 1992
Funds	$250,000

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. 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 7. Prepare a final report documenting the research.

Tasks 1 through 5 have been completed. Efforts are currently focused on Tasks 6 and 7.

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 L. Newman

Effective Date: February 28, 1990

Completion Date: February 27, 1992

Funds: $190,000

Designers are not normally required as part of the highway design process to indicate their assumptions regarding expected life and maintenance requirements for the facilities they are designing. Inadequate consideration for maintenance during design was recognized some years ago as evidenced by the following quotation from the Iowa Highway Maintenance Study (1959-1960, *HRB Special Report 65*): "From the beginning of highway maintenance, its heritage has included taking care of problems unknowingly or neglectfully perpetrated by design and construction engineers." This 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 routinely 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 the highway components. There is a need to specifically identify and communicate maintenance problems that can be addressed through better design. The need is accelerating because of the greatly increased volume of traffic that makes it difficult to close traffic lanes for routine maintenance work. It would be desirable to design highway components (such as pavements, bridges, drainage features, and roadside appurtenances) with zero maintenance requirements, but because this is unlikely, designs should be developed to ensure maintainability at optimal costs. Designers must consider a variety of issues such as: (1) access for inspection and repair; (2) incorporation of sensing and monitoring devices; (3) future maintenance operations, for example, snow removal, street cleaning, and mowing; (4) life expectancy of various materials and designs; and (5) improved features and configurations.

The objectives of this study are threefold: (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 each design; and (3) list and describe design details that create maintenance problems and improvements that overcome them, including opportunities for applying new technology. Attainment of these objectives will necessitate at least the following tasks.

Task 1. Through literature searches, interviews, and other appropriate means, determine current practices to do the following: (a) incorporate maintenance considerations in design procedures, (b) determine expected service life and future maintenance costs to support design decisions, and (c) identify details of specific problems and solutions to those problems. Select five agencies with successful programs, representing a variety of administrative structures, agency sizes, and geographical locations, for more detailed visits and interviews with maintenance and design engineers.

Task 2. Develop a process, taking into account the organizational structures of the agencies, to evaluate the maintenance implications of highway facility designs. The maintenance assumptions used in each design, for example, the expected service life of significant components, must be recognized. Such factors as future maintenance resource requirements and ease of future inspection and maintenance shall also be considered. Submit to the NCHRP for approval a recommended evaluation process and the name of a state willing to cooperate in the application of the process to a recently designed project. (Upon submission, it is anticipated that the necessary review and approval will be completed within 2 months.) On approval, apply the process to the selected state, document the results, and make modifications to the process if needed.

Task 3. Identify design features that will mitigate future maintenance, including techniques or devices that can be incorporated in the design of new facilities that will permit the monitoring or inspection of various components. Examples include techniques and devices to monitor or allow the inspection of the condition of post-tensioned cables, corrosion of steel, scour around foundations, and deterioration of concrete. All recommendations should be limited to those that can be practically employed in the immediate future.

Task 4. Prepare a final report documenting the findings of the research effort. The report shall include the state of practice and a user's manual. The user's manual will include the suggested maintenance evaluation process for highway facility designs and descriptions of design features, techniques, and devices to reduce or improve the maintenance of highway-related facilities and operations.

Research is essentially complete; the preliminary draft report has been submitted and is under review by the NCHRP project panel.

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 the preparation of practical guidelines for use by state highway departments.

The objective of this research is to prepare guidelines for the development, implementation, and administration of maintenance contracts. This objective will be accomplished by completing the following tasks:

Task 1. Through literature reviews, surveys, and interviews with contracting agencies and contractors, determine current practices to include as a minimum: (a) methods of deciding whether maintenance activities should be performed with contractors or in-house personnel (special emphasis shall be placed on determinations of comparative costs); (b) procedures for evaluating minimum staffing requirements for contracting agencies; (c) types of maintenance contracts being used by public agencies and reasons why; (d) innovative funding methods and sources to support certain types of contract maintenance work; (e) recent developments and unique methods in contract administration that include such issues as pay items, methods of measurement, incentive and liquidated damage assessments, project acceptance, and final payments; (f) unique methods of contracting for maintenance; and (g) agency satisfaction with various types of maintenance contracts. (This research is intended to update and supplement two relevant documents, *NCHRP Synthesis of Highway Practice 125,* "Maintenance Activities Accomplished by Con-

tract," and *A Guide for Methods and Procedures in Contract Maintenance* (prepared by the AASHTO Highway Subcommittee on Maintenance).)

Research is complete. The agency final report will be published as NCHRP Report 344, "Maintenance Contracting." The report documents the research effort, which was principally the examination of existing state and provincial (Canada) highway department practice, on which guidelines for the contracting of maintenance activities were based.

Project 14-9(4) FY '91

Role of Highway Maintenance in Integrated Management Systems

Research Agency: Cambridge Systematics, Inc.
Principal Invest.: Dr. Michael J. Markow
Effective Date: April 15, 1991
Completion Date: January 14, 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 standalone document.

Research is underway both at Cambridge Systematics and through a subcontract with The Urban Institute. Early efforts have concentrated on the first three tasks.

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: July 30, 1992
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.

Through December 31, 1991, research on the project has progressed on schedule. Questionnaires have been widely distributed to transportation agencies, maintenance contractors, and governmental authorities in order to identify all factors that must be considered in the performance of the research. The response to the questionnaires has been good and will assist the researchers in the development of the cost quantification framework.

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: April 30, 1992
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.

Research is well underway with activity on Tasks 3 and 4 now progressing. Surveys of state and local maintenance professionals have been done to develop profiles and perceived training and educational needs. This information is the basis for Tasks 3 and 4.

Project 14-10 FY '89

Improvements in Date Adjustment Technology for Maintenance Management Systems

Research Agency: The Urban Institute
Principal Invest.: William A. Hyman
Effective Date: May 29, 1989
Completion Date: October 14, 1992
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.

Phase II, as described above, began on April 15, 1991. Work under Tasks 1, 2, and 4 has begun to include communications with the Arizona, Connecticut, and Maryland highway departments. These three states have agreed to support demonstration projects.

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:	March 31, 1992
Funds:	$200,000

The objective of this research is 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 is 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 will require 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 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.

Tasks 1 through 5 have been completed. Efforts are currently focused on making final arrangements for the pilot presentation to be conducted in the state DOT. The interim panel meeting will be held in conjunction with the pilot presentation.

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 may request 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, 1992
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 underway with work commencing on the enhancements and the establishment of the bulletin board system.

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: June 30, 1992
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 maintenance). 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.

Tasks 1 through 5 have been completed including additional efforts to validate findings using HSES database. A draft final report has been submitted and is being reviewed by the project panel.

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, as used here, includes 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 of geosynthetics 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.

It is anticipated that the research will include, as a minimum, 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.

Research is well underway. The Task 3 Interim Report was submitted and approved. The research agency has found a high level of cooperation among state highway agencies, and have exhumed more than 80 geosynthetic drainage sites throughout the nation. Samples from these field sites are undergoing forensic examination. Three candidate laboratory tests to predict long-term behavior of

geosynthetics have been formulated and are being evaluated.

Project 15-14(1) FY '92

Intersection Sight Distance

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (30 Months)
Completion Date:
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 recommended 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.

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: August 31, 1991
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.

The final report has been received and is being reviewed. It is expected that it will be published in 1992.

Project 17-9 FY '92

Effects of Highway Standards on Safety

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (21 months)

Completion Date:
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. The final user's manual shall be prepared as a stand-alone document.

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 Scott A. Sabol	
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

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 6. Additional information on the project may be found in Research Results Digest 182.

Project 20-6 FY '69 and continuing

Legal Problems Arising out of Highway Programs

Research Agency: Transportation Research Board
Principal Invest.: Dr. Ross D. Netherton
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

A major and continuing need of State highway departments involves the assembly, analysis, and evaluation of operating practices and the legal elements of special problems involving right-of-way acquisition and control and highway law in general. Individual State experiences need to be compared and made available for possible application nationally. Need exists with respect to both immediate and longer-range right-of-way and legal problems.

In spite of this critical need, there has been no present mechanism that is capable of responding in time to be of practical assistance to State highway departments. The Right-of-Way and Legal Affairs Committee of the American Association of State Highway Officials has tried all of the known channels in an effort to initiate such research, but the response has been negative for one reason or another.

Accordingly, State highway officials have agreed that an appropriate mechanism be initiated under which needed research of the type suggested can be undertaken and with dispatch. Prototypes of such a device may be found in the various AASHO and HRB road-test projects that have been undertaken and, perhaps more closely related, in the 1956-60 special HRB Highway Laws Project.

NCHRP Project 20-6 has been established to meet the aforementioned need and is a continuing effort involving research on a priority listing of topics selected by the cognizant NCHRP project committee.

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 which 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. For the convenience of those individuals possessing the compendium, the Legal Research Digest is 3-hole punched for retention in a binder, as a ready reference, pending receipt of subsequent addenda.

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 to include the preparation of Addendum 5 to *Selected Studies in Highway Law.* Additional information on the project may be found in Legal Research Digest 19.

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
$250,000	FY '92

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 and 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 are 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 was completed in 1990 and published and distributed by AASHTO in early 1991. The consultant submitted a final version of a fracture control plan for the D1.5 code in August 1991. It was forwarded to the AASHTO Highway Subcommittee on Bridges and Structures' Technical Committee for Welding, where action may be taken on it in mid-1992.

Task 35, "Review of Traffic Signal Intensity Standards." 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 on *Vehicle Control Signal Heads* to better meet in-service 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 will be 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. The objectives are to develop a synopsis and critical evaluation of completed and on-going research efforts pertaining to high pressure truck tires and to identify future research required to fill information gaps in this area. 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. The 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 is to completely revise and expand the AASHTO *Guidelines on Pavement Management* (1985), incorporating the latest theory and practices. The new guide will give effective guidance to states that are in the early phase of Pavement Management Systems (PMS) 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. 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 is 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 is now being considered for adoption by AASHTO.

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 will be 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, has been added to the research team to provide assistance.

Task 42, "Development of National Truck Size and Weight Policy Recommendations" (TRB Division B). The objective of this study 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." Cancelled.

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 has 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 for consideration by the Subcommittee.

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 Guide Specification was initially adopted by AASHTO in 1983 but was based on work completed in the late 1970's. Since that time, relatively few revisions have been made to it. However, a substantial amount of new knowledge has been gained concerning seismic design and the seismicity of the Eastern and Central United States. Therefore, this task was initiated to provide the basis for reviewing and revising the provisions in the Guide Specification as necessary. Work on the task was initiated in May 1991 and is scheduled to be completed in July 1992. Through the end of 1991, the research identified the major areas in need of revisions in the specification and work has been started on developing new design provisions.

Task 46, "AASHTO Guidelines for Bridge Management Systems." The AASHTO *Guidelines for Pavement Management Systems* was published in 1990 based on work completed under NCHRP Project 20-7, Task 38. AASHTO has 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. Work on this task was initiated in April 1991 and will be completed in January 1992. Through the end of 1991, 2 drafts of the guidelines have been completed and revised. The final draft is expected in early 1992, at which time it will be submitted to the AASHTO Standing Committee on Highways for consideration.

Task 47, "Support for the Joint Committee on Truck Size and Weight" (Dr. Michael D. Meyer). AR-3-89 called for AASHTO to form a Joint Committee on Truck Size and Weight, charged with the goal of developing a long-term freight transportation strategy. A Steering Committee was established, and a Workshop on Freight Policy 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. AR-2-91 broadens AASHTO's efforts in this area by calling for a Joint Committee on Domestic Freight Policy, rather than a Joint Committee focusing specifically on Truck Size and Weight. This task will also encompass Dr. Meyer's efforts in connection with his coordination of Task 50.

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. 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, and the agency's principal investigator introduced the project to the Highway Subcommittee on Construction during the Subcommittee's 1991 summer meeting. A survey of state practice and interest in standard specification formats is underway. Interviews of selected state personnel have commenced. As a demonstration, sections of the current AASHTO *Guide Specifications for Highway Construction* are also being reformatted to provide comparisons and help determine the effort that would be involved.

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. A meeting was held during the 1991 TRB week, at which plans to construct test sections of SMA were discussed. Byron Lord is coordinating the FHWA efforts in this area. At the request of Colorado DOT funding is being made available for travel expenses for an engineer with CO DOT to visit the LCPC facility near Nante, France, for on-site inspection and training in connection with the asphalt testing equipment that is being purchased. Upon return to the U.S., a report on the equipment, its purpose, use, benefits, etc., will be prepared. 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.

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 will examine the state's implementation concerns of permitting LCV's on a national system. The impacts of such vehicle use will be summarized, including increased productivity, pavement savings/costs, bridge costs, safety implications, traffic capacity and congestion, modal diversion, and environmental costs. State experience where such vehicles are currently allowed will be incorporated into the paper. Alternative means of allowing LCV's will be examined, and guidance prepared to those states which are currently trying to respond to requests for such permitted use. The paper will not lead to specific recommendations, but instead, by presenting alternatives and discussing the pros and cons of each, governments currently facing decisions relating to LCV highway use will have in one document suitable information that will inform these decisions. To ensure the credibility of this study is not questioned by interested parties, 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., has been selected for this task. An outline and schedule has been prepared, an initial coordinating meeting was held, a questionnaire is being formulated, and preparation of the draft of the paper is progressing.

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 would do just that. The synthesis would review the literature and provide 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 will provide a valuable source document for the soon-to-be established AASHTO Joint Committee on Domestic Freight Policy. Barbara Harder has been appointed as a consultant to undertake this task.

Task 52, "Support for the Joint Committee on Domestic Freight Issues" Responding to Resolution AR-2-91, AASHTO is in the process of forming a Joint Committee on Domestic Freight Policy. The Joint Committee, composed of more than 35 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.

Task 53, "Profilograph Limitations, Correlation and Calibration Criteria for Effective Performance Based Specifications." 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 task will likely commence in early 1992.

Task 54, "Financial Impacts of Conversion to the Metric System." The AASHTO Standing Committee on Highway's Task Force on Metrication requested this task in order to provide an analysis of the overall costs that states will incur by converting to the metric system. The work will identify factors that must be considered in metrication and, through a survey of the states and associated analysis of survey results, quantify the costs of conversion. The task will consider costs involved in converting signs, specifications and standards, computer programs, and other items pertinent to state transportation departments. Input will be solicited from Canada, a country that has gone through the conversion. The advisory panel for this task will be the Task Force on Metrication. The project will likely commence in early 1992.

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 stand-alone 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.

Preliminary final documentation has been reviewed by the NCHRP. The agency is now addressing the review comments and preparing revised final documentation. The resulting software from this project will be available on a bulletin board system and maintained by the National Geodetic Survey.

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).

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. Michael S. Bronzini
Effective Date: July 1, 1990
Completion Date: October 31, 1991
Funds: $200,000 (Phases I & II)

Recent trends reflect an alarming decline in the number of civil engineering students entering and graduating from our colleges and universities. In state highway agencies alone, the need for civil engineers, who comprise almost 75 percent of the professionals hired, is projected to grow at the rate of about 4.9 percent per year. Because transportation agencies are one of the major employers of civil engineers the projected shortage will impact directly on them.

To meet the coming shortage of civil engineers, agencies must begin planning now for the future recruitment and retention of civil engineers. Better ways must be found to ensure an adequate supply of qualified civil engineers in an environment of declining enrollments and changing demographics. An AASHTO (American Association of State Highway and Transportation Officials) task force has been appointed and is addressing the issues of recruitment and retention of civil engineers by transportation departments. This NCHRP project is designed to increase the supply of civil engineers now and in the future, and will complement the AASHTO effort.

The objective of NCHRP Project 20-24(3) is to identify, develop, and test specific methods that will increase the overall supply of civil engineers available to transportation, as well as other, agencies in the coming decade and into the next century. Recognition must be given to expected changes in the demographics of the labor force. To accomplish this objective, the 3-phase process described below is envisioned.

Phase I—Gather Data

Task 1. Identify and assess present practices that are being used to increase the interest in civil engineering and the overall supply of civil engineers.

Task 2. Identify and assess practices used by other professional disciplines that are or have been found to be effective in expanding their overall labor supply.

Task 3. Conduct surveys of groups including, but not limited to, civil engineers in transportation agencies, civil and other engineering college students, engineering faculty, junior and senior high school students, and guidance counselors. Determine the attitudes and expectations of students, teachers, and guidance counselors; the degree of awareness of civil engineering as a discipline and career

alternative; the perception of what a civil engineer does; and other issues that will be helpful in designing programs to increase the appeal of civil engineering. The surveys may also provide insight into the success of past practices to attract civil engineers. Specific recognition also must be given to the problems and barriers facing minority, immigrant, and female civil engineering candidates and to the expected changes in the overall demographics of the labor force.

Task 4. Document in an interim report the activity completed under Tasks 1, 2, and 3.

Phase II—Recommend Plan of Implementable Actions

Task 5. Evaluate the results of Phase I to determine what works and why, what does not work and why, and what will work in the future and why.

Task 6. Recommend a series of potential actions for increasing the supply of civil engineers. A write-up of each recommended action will contain, as a minimum, the following information: (a) title and summary description, (b) specific objectives, (c) detailed description of how to implement, (d) required resources for implementation, (e) responsible party, (f) target group, and (g) discussion of effectiveness. If the action is already being used, references and additional source materials will be identified. If the action needs to be developed, the anticipated resources required and the likely responsible agency(s) must be defined.

Task 7. Document the results of Phases I and II in a final report. The final report will include an appendix that contains all the recommended actions from Task 6. (A draft final report will be reviewed by the NCHRP for acceptance and the selection of actions to be developed further under Phase III. The final report will then be modified accordingly and resubmitted, whereupon immediate distribution of the final report by the NCHRP is expected. The pursuit of Phase III will be at the discretion of the NCHRP.)

Phase III—Produce a Manual of Selected Techniques

Task 8. Develop, test, and refine the selected actions.

Task 9. Produce a manual of the selected actions for immediate use by transportation agencies, educational institutions, national organizations, and others. In addition to the manual, supplemental material may be necessary for specific actions.

Phases 1 and 2 are complete and the agency's final documentation, which is comprised of 2 reports (a summary report and the final research/resource report), has been submitted. This final documentation, now in the editorial and publication process, includes (1) a recommended list of actions to increase the awareness of civil engineering as a profession, improve the retention of civil engineering candidates, and enhance the curriculum of pre-college and college programs; (2) a catalog of existing related programs; and (3) the results of 17 focus groups.

The agency has been requested to submit a Phase III proposal that will expand on the recommended actions from the first 2 phases and produce pilot material for a limited number of the recommended actions. It is expected that the pilot material will be tested as part of AASHTO's newly established pilot project, the TRAC (Transportation and Civil Engineering) Careers Center.

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. Decisions regarding NCHRP publication of the report or parts of it are pending.

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 will require at least the following tasks:

Task 1. Identify problems of communication between state transportation departments and the public based on opinions of senior state DOT managers and other information sources. There shall be contact with chief administrative officers, top managers, and public affairs officers of state transportation departments. Personal contacts during such events as American Association of State Highway and Transportation Officials or Transportation Research Board meetings are also encouraged.

Task 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. Guidance shall be given on how to choose the most appropriate technique for a specified application. The toolbox will provide transportation departments with a coordinated body of practical information for designing communication programs for their departments.

Task 3. Using results from Tasks 1 and 2, 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. For planning purposes, 2 months will be required for the review and approval of the recommended package. A meeting with the NCHRP approximately halfway through the review period is anticipated.

Task 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.

Task 5. Demonstrate the prototype at, or in conjunction with, an AASHTO meeting involving top level managers of state transportation departments. Demonstrations at other meetings such as TRB are encouraged. Based on these demonstrations, make necessary refinements to the prototype, and toolbox if necessary.

Task 6. Prepare a final report that fully documents the conduct of the research. The report package shall include as stand-alone items the Task 2 toolbox of techniques and the Task 4 prototype materials. The final report will also contain recommendations for the distribution of the entire final report package, or components of it, beyond methods traditionally used by NCHRP.

Tasks 1, 2 and 3 are being done concurrently with the Task 3 prototype recommendations expected in early 1992. As a means for gathering information under Task 1, the principal investigator has interacted with the AASHTO Administrative Subcommittee on Public Affairs during its summer meeting in Baltimore, Maryland and at the October 1991 AASHTO annual meeting in Milwaukee, Wisconsin. Also, during the AASHTO annual meeting, several DOT chief administrative officers were interviewed for their opinions. Research progresses as scheduled.

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:	April 30, 1992
Funds:	$49,786

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 a vast organization with numerous functions and departments. In order 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 department. This information is logically linked to the more important question: Where can the CAO enact change to improve agency performance? Although particularly important to new CAOs, the question of performance is important to administrators. Agency-performance information is a powerful analytical tool for existing CAOs in tracking their own performance over time and, perhaps, for generally comparing their state to others.

Private sector corporations use performance monitoring extensively in the decision-making process. They track performance at the micro level (e.g., individual employees and computer networks) and at the macro level (e.g., departments and business areas). Performance indicators, such as revenues and profit margins, are used to allocate resources, enact structural change, and support personnel and other actions. In many ways, running a state highway or transportation department is similar to running a large corporation, and targeted performance information would be a valuable tool for the administrators who must run these organizations.

The specific objective of this project is to produce 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. This compendium will include performance measures and indicators most commonly used by individual states and provide a recommended composite list of measures and indicators with synthesized definitions that could be acceptable to a large number of states. It is recognized that there are many terms and secondary performance indicators that an agency may use. The contractor should focus on those that appear to be most common. The purpose here is not to develop new performance measures or indicators, but rather to identify, collect, and categorize measures by transportation mode. The project objective will require at least the following tasks:

Task 1. Survey all state highway and transportation departments for commonly used performance measures or indicators and for glossaries of such terms. Construct a summary of this information.

Task 2. Compile a list of recommended measures and indicators used by state highway and transportation departments. Describe these measures and indicators in terms and with definitions that satisfy the greatest number of departments.

Task 3. Distribute the summary and synthesized list for review by state highway and transportation departments for accuracy and application to their individual departments. A "delphi" approach may be necessary to develop measures and indicators of performance that achieve the highest degree of acceptability to as many states as possible.

Task 4. Prepare a final report documenting the research effort. Appended to the final report will be the compendium of summarized and synthesized performance measures and indicators with their appropriate definitions.

The Task 1 survey has been mailed and the agency is awaiting responses before commencing with the remaining tasks.

Project 20-24(6)B FY '91

Business Systems Plan for Highway Engineering Information

Research Agency: PRODATA, Inc.
Principal Invest.: Grant Reynolds
Effective Date: August 26, 1991
Completion Date: May 25, 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 are 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 will require 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.

Tasks 1, 2, and 3 are underway. To ensure the correctness and the applicability of the research, the principal investigator has met with AASHTO's Joint Development Task Force at the October 1991 AASHTO annual meeting and with representatives of the Task Force at an ad hoc meeting in Chicago, Illinois on November 23, 1991.

Project 20-24(7) FY '91 & '92

Alternatives to Motor Fuel Taxes for Financing Surface Transportation Improvements

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (22 months)
Completion Date:
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 policy-makers 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.

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: January 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 lesson-plan outlines will form the basis for comprehensive training packages, some of which will be devel-

oped 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.

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: March 31, 1992
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 oper-

ation 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.

Task 1 through 3 have been completed. The panel approved the interim report and recommended its publication, which led to Research Results Digest 180. The agency is nearing completion of Tasks 4 through 6, with the expectation that the project will be completed in the first quarter of 1992.

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:	February 1, 1992
Funds:	$300,000

When constructing or improving highway projects, state highway agencies are encountering hazardous waste sites in highway rights-of-way with increasing frequency. Although one or two states have considerable experience addressing these problems, few state highway officials are aware of the regulatory or technical issues raised. Little information is available to help highway officials assess the potential delays and costs likely to be encountered, or to suggest approaches to managing the problem. Accordingly, the states, acting through the American Association of State Highway and Transportation Officials (AASHTO), have requested guidance on how to assess the potential cost and delay of hazardous waste site cleanup to assist in their decision-making on whether and how to proceed with construction projects that involve a hazardous waste site. A study committee including experts in highway design and construction, hazardous waste remediation, environmental law, environmental health, and public policy will build on a previous survey of state problems and commission a small number of case studies to examine and characterize the problems being encountered by state highway agencies. Drawing on these findings and the experience and expertise of its members, the committee may provide guidance to state highway officials on managing hazardous waste site problems. The committee may also identify areas where changes or improvements in state or federal procedures are justified. Aspects of this issue

where uncertainty is high due to lack of technical knowledge will be indicated and research recommended. Aspects where uncertainty is high because of legal and regulatory requirements will also be discussed.

The policy study is nearing completion. The study committee reviewed a draft final report at a December 9, 1991 meeting. As a result, revisions are now underway for the final version.

Project 20-29 FY '92

Development of a Multimodal Framework for Freight Transportation Investment: Consideration of Rail and Highway Trade-offs

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (18 months)
Completion Date:
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.

AREA 21: TESTING AND INSTRUMENTATION

Project 21-3 FY '90

Instrumentation for Measuring Scour at Bridge Piers and Abutments

Research Agency: Resource Consultants, Inc.
Principal Invest.: Dr. Everett V. Richardson Dr. Peter F. Lagasse
Effective Date: December 4, 1989
Completion Date: March 3, 1992
Funds: $299,824

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 expedi-

tious 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. It is anticipated that the research will include the following tasks:

Task 1. Review relevant current domestic and foreign practice, performance data, and research findings. The review should be comprehensive and also consider technology transferable from sources other than the highway industry. Perform a survey of equipment that has been previously proposed for bridge scour monitoring.

Task 2. Identify electrical, mechanical, or other devices that can be adapted to measure maximum scour at bridge piers and abutments. These existing, proposed, or conceptualized devices must meet the following criteria:

- 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.

The following criteria are desirable for the 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.

Task 3. Evaluate each device identified in Task 2, noting its advantages, limitations, anticipated purchase and installation costs, and important features and considerations. Identify possible scenarios for equipment problems and failure. Select devices that show promise for further development and testing.

Task 4. Document the findings of Tasks 1, 2, and 3 in an interim report to be submitted not later than 9 months after initiation of the study. The interim report shall include a test plan for evaluating the devices selected at the conclusion of Task 3. Provide a cost estimate for developing and testing each identified device. NCHRP approval of the interim report and test plan will be required before proceeding with the remaining tasks.

Task 5. Develop prototypes of the devices approved by the NCHRP.

Task 6. Test and evaluate the prototype devices.

Task 7. Prepare a cost analysis for the fabrication, installation, operation, and maintenance for each prototype evaluated.

Task 8. Submit a final report documenting all research findings, including recommendations for a field evaluation program for prototypes that show promise. The final report should also include an estimate of the costs and time for performing field evaluations.

Research on the project has been completed. The final report has been submitted for project panel review and includes recommendations on devices and concepts that warrant further development and evaluation. The project panel will review these recommendations and then determine whether to initiate a follow-on phase of work for which AASHTO funding has already been allocated. The follow-on phase will perform field evaluations of the recommended devices and systems in order to determine their long-term performance characteristics, and whether or not problems exist with the installation and maintenance of various devices. The report and recommendations will likely be published in the regular NCHRP report series.

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: June 30, 1993
Funds: $300,000

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 groundwater 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 underway both at Strata Engineering Corporation and through a major subcontract with the University of Massachusetts at Amherst. Early efforts have been concentrated on Task 1. In May 1991, several members of the project research team made presentations at the TRB Special Summer Meeting on Geotechnical Exploratory Holes, a meeting held in conjunction with the 42nd Annual Highway Geology Symposium.

Project 21-5 FY '92

Determination of Unknown Subsurface Bridge Foundations

Research Agency: Contract Pending
Principal Invest.:
Effective Date: (33 months)
Completion Date:
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 charac-

teristics 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.

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.

Tasks 1 through 3 have been completed. The draft final report has been submitted and reviewed by the project panel. Comments have been forwarded to the research agency.

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:	May 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 research agency has addressed the comments received on the second draft report after a review by about 90 people. The panel met to review the comments and resolve any remaining issues. Efforts are underway to complete the final version of the report.

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:	June 30, 1992
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 modifications to the software have been completed and revised tables have been generated. Efforts are underway to compare the revised tables with the old and assess

the implications of extending the multiple performance concept to other longitudinal barriers.

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: November 30, 1993
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.

Project 22-10 FY '91

Updated Materials for a Traffic Barrier Hardware Guide

Research Agency: Momentum Engineering, Inc.
Principal Invest.: Kathleen Hancock
Effective Date: January 2, 1991
Completion Date: March 31, 1993
Funds: $200,000

A June 1979 publication, entitled "A Guide to Standardized Highway Barrier Rail Hardware," was prepared by the AASHTO-AGC-ARTBA Joint Cooperative Com-

mittee. 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.

The agency has submitted the interim report and is reviewing the barrier details received from the states.

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.* It is expected that AASHTO will consider the recommended specification and commentary provisions for adoption in 1992.

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, 1992
Funds:	$300,000

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.

Research is underway. Current practice and literature on methods of reducing downdrag forces in piles using bituminous (and other viscous) coatings have been reviewed, and a background summary and a complete bibliography have been prepared. A preliminary Design and Construction Manual based on the present state of the art has been submitted. Field and laboratory programs to verify design and construction recommendations are un-

derway. Instrumented piles are in place and are being monitored on projects in Alberta, Canada, and New Orleans, Louisiana. Laboratory tests include the rod shear test on bitumen, the flow test, the dynamic (driving) test, the freezing test, the particulate penetration test, the rheometer test, and tests of coating techniques. 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.

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: April 15, 1991
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; construction 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.

A draft of the Task 4 "Wetland Replacement Process Manual" has been submitted and reviewed during a project panel meeting on December 11 and 12, 1991. A revised version of the manual as well as preliminary documentation of the entire research effort is now underway.

Project 25-4 FY '92

Determining Economic Impacts on Adjacent Businesses Due to Restricting Left Turns

Research Agency: In developmental stage
Principal Invest.:
Effective Date: (27 months)
Completion Date:
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 the 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 proeprty owners, due to restricting left-turn movements. The scope of the research will include: (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. The most likely sources of information are publications of the Urban Land Institute, International Right-of-Way Association, Society of Real Estate Appraisers, American Planning Association, and Institute of Transportation Engineers. Other general sources would be publications and articles from private industry, trade associations, and regional and local government organizations. Document the results and assemble an annotated listing of key items. (2) Develop a plan for conducting the field studies. State and local highway agencies may have to be canvassed to obtain appropriate study sites. It is anticipated that 20 sites can be included. (A site is defined as a highway improvement project of approximately 1 to 3 miles in length with 20 or more affected businesses.) 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. Data gathered from these sites should include but not be limited to the following: general roadway layout, traffic patterns and volumes, local demographics, land use types, patron surveys, changes in sales, land value, lease losses, vacancy rates, and zoning changes. 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 sophisticated 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 methodology 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 through 5. The report will summarize the findings, illustrate the application of the Task 5 methodlogy, 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.

Project 25-5 FY '92

Remote Sensing and Other Technologies for the Identification and Classification of Wetlands

Research Agency:	Contract Pending
Principal Invest.:	
Effective Date:	(Phase I—11 months, Phase II—18 months)
Completion Date:	
Funds:	$300,000 (Phase I—$100,000, Phase II—$200,000)

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 technolo-

gies. 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.

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